A CONTRIBUTION TO THE STUDY OF EVALUATING DAIRY CATTLE.

by

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THE RELIABILITY OF DIFFERENT SYSTEMS OF MILK RECORDING.

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INTRODUCTION.

The problem of obtaining an accurate quantitative measure of the inherited productive ability of the dairy cow has occupied the attention of dairymen since very early times. According to MORSE (1910), one of the first to realize the importance of such a measure was PYRRHUS, who as early as 300 B.C. measured milk from cows that produced approximately 40 litres per day (88.40 lbs.). Little developments however in methods of estimating milking capacity took place until about half a century ago but since then much consideration has been given to the subject.

It is realized that the most accurate method of determining a cow's yield is to weigh and test her milk daily, but such practice is very unusual as it is practically impossible to do so for every cow in a large herd, in view of the labour and expense involved. Thus the many different systems of milk-recording in use at the present time are results of attempts by each country, or milk-recording society to devise short-cut methods of estimating the lactation yield of milk and fat as accurately as possible, and at a minimum cost.

Milk recording is the method of determining the performance of an animal from the results of periodic tests made during the course of a day or sometimes several consecutive days; and repeated at definite intervals. The results of these tests form the basis on/

on which the total yield of the animal is estimated.

The different methods of recording are based on the assumption that the milk and fat yield on the days between the tests are the same as on the days when the tests are carried out. It is known, however, that during the course of lactation, a cow's yield is subject to considerable variations both in quantity and in fat content. These variations are of two kinds, namely regular, that is, due to the characteristic changes in the lactation curve, and irregular, caused by the different environmental factors. Owing to these variations it cannot be expected that the total lactation yield, as determined by a calculation based on the results of the periodic tests, will be identical with the quantities of milk and fat actually produced by the animal during that lactation. Therefore, the results obtained by the different methods of milk recording are to a greater or less degree divergent from the reality, and the standard of accuracy is in accordance with the methods used in each case.

FACTORS WHICH INFLUENCE THE ACCURACY OF THE METHOD OF RECORDING.

Most of the writers who have studied this subject have realized that the factors which influence the accuracy of any system of milk recording are as follows:

1./

1. Frequency of the recorder's visits.

The extent of agreement between the actual yield and that calculated from the tests depends largely on the frequency of the recorder's visits, i.e. on the length of the intervals between tests. The shorter the intervals between tests the more accurate are the results; but the difficulty is to find a period which can be considered satisfactory from both the scientific and the financial points of view.

2. Length of each test.

It is understood that tests of longer duration will give more accurate results, but our aim is to find a method which will combine accuracy with economy and prove to be practicable.

3. Position of the test period in the test interval.

In consequence of the regular variation in the production of a cow during the course of one lactation the position of the test day or days in each "testing interval" is of considerable importance for the calculation of the total production of the lactation. By "testing interval" is meant the time for which the record is considered as representative. The record is sometimes considered as representing the yield of the days preceding the day or days of testing; in this case the actual period of testing is considered as terminating the test interval; in certain cases on the/

the other hand the test period (a day or more) is regarded as beginning the following test interval. The day or days of test may also be considered as situated in the middle of the test interval. Therefore the calculated yield differs to a greater or less degree from the actual performance according to the situation of the test period. However, it is accepted by most of the writers that the best agreement between the two yields is obtained when the test period falls in the middle of the test interval.

4. Methods of calculating the total yield.

The different methods of calculating the total yield of a lactation based on the results obtained have great influence on the accuracy of the records. This point has only recently been the subject of careful study, for it was not considered of great importance. It is now recognized that a great proportion of the errors formerly attributed to the previous factors, e.g. frequency of testing and duration of test periods, is more justly attributable to the methods of calculating employed.

5. Inaccuracies due to the weighing and measuring of the milk and to the reading in the fat test.

Attention has often been drawn to the fact that errors made in weighing and especially in inexact reading in the fat test are at least as important for the/

the final results as errors due to the other factors. These errors, however, are well known in practice and can only be avoided if the tests are carried out with scrupulous care and honesty.

6. <u>The determination of yield at the beginning and end of the lactation.</u>

The difference between the calculated and the actual yield during the course of one lactation may be largely due to the inexact determination of the yield at the first and the last test intervals. It is generally found that the yield of cows during the first few days after calving and before drying, shows irregular variation and cannot therefore be used as the basis of performance for a prolonged period of time. Also the length of the first and last intervals should be estimated accurately as in some cases they may be a few days longer or shorter than the specified length.

PREVIOUS INVESTIGATIONS AND THEIR RESULTS.

During recent years the accuracy of different methods of milk recording has been the subject of numerous investigations in different parts of the world. In any consideration of the reliability and accuracy of the records, special weight must be given to/

to the maximum error which may occur. Next in importance, is a knowledge of the frequency of the error and its standard deviation. Thirdly, the mean error of each method must be known.

The safest method of determining the accuracy of the records is to compare them with the actual performance of each cow, which is established by measuring each milking separately and testing its fat content. Most writers who have studied the problem have, in fact, adopted this method, and some of them, for some reason or other, have compared the results obtained with different frequencies of recording, on the assumption that shorter intervals between tests would give more accurate results.

PABST (1851) pointed out the need for determining the yield of individual cows and recommended that milking tests should be made every two or four weeks.

MARTINY (1887), working on a breeding herd in Corinthia, compared the reliability of monthly tests with weekly tests carried out during one calendar year. All the weekly tests were done on a Wednesday. When the monthly tests were calculated from the yield of the first, second, third or fourth Wednesday of each month, the results for the yearly yield varied more or less considerably from each other, and from the performance calculated from the weekly tests. For example, in an extreme case there was a difference of 577 Litres/

Litres (1273 lbs.) between the four-monthly tests, the approximate annual yield of the animal being 2600 Litres (5738 lbs.).

Such figures can hardly be considered of great significance, since the actual yields of the cows were not estimated, and the method of calculating the total yield was to determine the average yield for all test days, and to multiply this average by the number of milking days. Such a method of calculation involves a certain degree of inaccuracy which makes the results incomparable with the others.

MARTINY came to the conclusion that a single monthly test is quite unreliable for determining the yield of a cow; also that an interval of 14 days between tests is too long and recommended a 7-day test at least.

MAEHRLEN (1880) reported that in order to estimate the yearly yield of a cow as accurately as possible, the test should always be carried out on the first day of the month; then the average from the figures of every two consecutive testings should be taken, multiplied by the number of milking days of the month in question and the results totalled to get the final figure. As regards the first month of calving, the author suggested that the yield recorded at the following test be taken as the basis.

It is of interest to note that such an early writer recommended/

recommended a method more or less implying the idea of placing the testing day in the middle of the test interval.

WIEDERSHEIM (1880), working with 7 cows, compared the figures derived from the monthly, fortnightly and weekly tests with the actual yield. He calculated the yearly milk yield obtained by any method by taking the average from the yield of the test days and multiplying it by the number of milking days. When the maximum error obtained was expressed as a percentage of the actual yield, it was found that in the case of monthly tests, there was a maximum deviation of 17.1% of the total performance, in fortnightly tests of 9.5%, and in weekly tests of 3.5%.

WIEDERSHEIM concluded that milk recording should be carried out at least weekly. Owing to the small number of animals and to the unusual method of calculating the total milk yield, the figures given cannot be regarded as reliable.

RHODE and EISBEIN (1885) in their text book stressed the importance of regular milk recording and stated that this can be done adequately by "undertaking so-called test milkings several times a month and in this way determining the yield of the individual cows". The authors believed that two tests a month are quite sufficient, as it was found that the results obtained in this way were almost the same as with weekly tests.

FLEISCHMANN/

FLEISCHMANN (1891), working on six cows from the herd of Schlieffen-Roden tested the findings of MARTINY (1887). When the records of monthly tests were compared with those of weekly tests, the maximum difference was found to be 361 Kg. of milk (796 lbs.), while the greatest difference between the results of weekly and fortnightly tests was 109.2 Kg (241 lbs.). As the average, lactation yield, according to weekly tests, was about 3000 Kg (6615 lbs.), the maximum error, expressed as a percentage of the total performance was 12% in the monthly tests and 3.7% in the fortnightly ones. The author concluded that in order to get reliable figures for calculating the annual yield and comparing the performance of individual cows, it is necessary to use weekly recordings.

SIEDEL (1891) recorded the daily milk yield for one lactation of 10 Black Pied cows at the Kiel Experimental Station, and compared it with the results of fortnightly, 10-day, and weekly tests. The test day fell either at the beginning or at the end of the interval. The total performance was calculated in two ways, namely:-

(a) by multiplying the figure obtained in each test by the number of days in the corresponding interval and adding up the results.

(b) by calculating the average yield for all test days and multiplying it by the number of milking days in the lactation period.

SIEDEL found that the maximum deviation of the calculated yield from the actual, expressed in percentage of the latter, equalled 14.0% for weekly, 11.85% for 10-day, and 16.95% for fortnightly tests. The actual lactation yield of the experimental animals averaged 3350 Kg. (7387 lbs.). No significant difference was found when the test was made either at the end of the interval or at the beginning; and the calculation of the total yield by method (b) was as accurate as that by method (a). The author recommends the fortnightly test as it gave as accurate results as the weekly, and for calculating the total milk yield he recommends the simpler method (b).

BACKHAUS in his investigation in 1892 to determine the accuracy of different systems of recording, made use of FLEISCHMANN'S data which consisted of milk and fat records of 16 cows. As regards milk yield, he found that the greatest deviation of the calculated yield from the actual was 3.24% with the weekly and 8.60% with the fortnightly tests. The actual lactation yield of the experimental animals averaged about 3000 Kg. of milk (6615 lbs.). BACKHAUS concluded that weekly milk records give entirely reliable results, whereas the fortnightly are less accurate, and records from tests made at longer intervals are naturally even less reliable.

In/

In the case of fat yield, the systems investigated were testing weekly, every third, every fourth, and every fifth week. The maximum deviation, expressed as a percentage of the actual fat yield during the lactation, equalled respectively 2.90%, 5.57%, 6.39% and 8.97%. The actual lactation yield of the experimental animals averaged about 90 Kg. of fat (198 lbs.). BACKHAUS reported that testing milk for fat percentage at 5 weeks' intervals is sufficiently accurate for practical purposes, if the figure recorded is taken for the milk yield of the week in question, as well as the two preceding and two following weeks.

WYCHGRAM (1897), using FLEISCHMANN'S data, studied the reliability of the milk and fat records obtained by testing twice a month. The tests were made on the 1st and the 15th of each month, and the lactation milk yield was determined by multiplying the yield on the test day by the number of days in the respective interval and totalling the results. The fat yield in the course of the lactation was calculated by multiplying the estimated milk yield for the month by the average fat percentage of the two tests and adding up all the monthly yields.

WYCHGRAM reported that the difference between the calculated yield and the actual, expressed in percentage of the latter, did not exceed 2.49% in the case of milk and/

and 4.79% for fat. He believes that results obtained from recording and testing milk twice a month are sufficiently accurate to form a basis of comparison between herds and for breeding purposes.

At Wisconsin Experimental Station, the daily milk and fat yields of six cows were recorded during the course of one lactation. FARRINGTON (1899) when analysing these data compared the actual yield with those obtained from weekly, fortnightly and monthly tests and found the maximum deviations to be respectively, 3.9%, 6.6% and 9.7% of the actual milk yield, while for fat yield the corresponding figures were 5.2%, 4.6%, and 10.4%.

In order to investigate the reliability of weekly and half-monthly records, KIRCHNAR (1899) recorded the daily milk yield of 14 cows during a calender year. In both systems of recording, the test day was taken in the middle of the interval. The calculated yield was compared with the actual, and it was found that in the weekly test the maximum deviation was 1.47% of the actual yield and in the half-monthly test, 6.14%. The actual milk yield of the experimental animals averaged about 2800 Kg. (6174 lbs.).

KIRCHNAR concluded that a half monthly test cannot give a sufficiently accurate estimate of the milk yield and it is better to have a weekly test as more frequent tests are impracticable owing to the labour/

labour and difficulties involved. He reported that the test day should fall in the middle of the test interval, because if the lactation curve is normal, the calculated yield would be too high if the test day fell at the beginning of the interval, and too low if it fell at the end. He gave some examples to illustrate his conclusions.

MARTINY (1899) used the results of daily tests, carried out for the purpose of comparing different methods of machine milking, in order to investigate in how far the results of weekly tests differ from actual yield. He established in a case of 10 cows recorded during 76 days, that the maximum deviation of the calculated yield from the actual was 3.0% of the latter for milk yield, and 4.0% for fat yield. In another test of milking machines, extended over 75 days and involving 24 cows, he established the greatest deviation of calculated yield from the actual of 7.35% for milk yield. In the third experiment, involving 10 cows and a period of 56 days, the maximum deviation of the results of weekly tests compared with the actual yield was 6.03%, and finally in a fourth experiment, involving 20 cows over a period of six weeks, the maximum deviation was 7.1% for milk yield and 9.5% for fat yield.

As a result of these investigations, MARTINY considers/

considers that all tests at longer intervals than weekly are inadequate. In his opinion, weekly tests may be sufficient in order to bring out the rough difference in the milking capacity of individual cows in a herd which is little uniform in this respect, but he thinks that in herds which are fairly uniform with regard to milking capacity, it is impossible to avoid daily recording.

It should be noted that the figures which MARTINY established in his four trials are variable and cannot be compared with the results of other studies as the yield was only recorded for a short period and not for a complete lactation. Also the results obtained with different milking machines may affect the figures.

In a paper read at the 5th International Dairy Congress, MARTINY discusses the reliability of the results of milk recording and again concludes that a weekly test at least is necessary when it is not possible to record daily.

ULLMANN (1906) analysed the records of 20 cows during one year and tested the reliability of the results obtained from weekly, 10-day, fortnightly, half monthly, 20-day and monthly tests. Contrary to the other authors, **ULLMANN** did not compare the results obtained **by** applying these systems of recording with the actual yield because he found this method inadequate.

He/

He believed that it is better to determine by how many kilograms the existing difference between the yields of two cows is increased when the performance is estimated by different methods of recording. He concludes that, as well as the weekly test, 10-day and fortnightly tests are entirely satisfactory, but longer intervals are unreliable.

ULLMANN also investigated the effect of the position of the test day upon the accuracy of the results, and contrary to KIRCHNAR and most of the writers he came to the conclusion that the most accurate results are obtained when the test day lies at the end of the corresponding interval and the least accurate, when it lies at the beginning. A test day in the middle of the interval does not, according to ULLMANN, increase the accuracy as compared with the test day at the end of the interval.

As regards the calculation of the total performance, the most reliable results were obtained by multiplying the yield for each test day by the total number of days of the interval involved and adding the results.

HERWEG (1911) undertook an investigation involving 150 cows, in which milk and fat yields were recorded fortnightly in order to determine the relative accuracy of 4-weekly records. The test day was selected so as to fall in the middle of the test interval, and the results obtained from the 4-weekly tests were compared with/

with those from the fortnightly. It was found that in 92% of the animals, the difference between the two calculated yields was below 150 Kg. (331 lbs.), while in 8% of the animals it was higher, the greatest difference being 480 Kg. of milk (1058 lbs.) and 8.2 Kg. of fat (18.1 lbs.). HERWEG concludes that 4-week tests are on the whole not to be recommended.

In another investigation HERWEG, using FLEISCHMANN'S data, compared the results obtained from 7-, 14-, 21- and 28-day tests with the actual yield. The maximum deviations were, respectively, 63 Kg. (139 lbs.), 128 Kg. (282 lbs.), 101 Kg. (223 lbs.) and 136 Kg. (300 lbs.) of milk and 2.2 Kg. (4.9 lbs.), 3.2 Kg. (7.1 lbs.), 5.2 Kg. (11.5 lbs.), and 7.9 Kg. (17.4 lbs.) of fat. The author concludes that the 21-day tests, in cases where local and economic conditions necessitate them, may be regarded as reliable and not inferior to 14-day, while 28-day tests should be introduced only in cases of necessity.

MARQUARDT (1911), expressing his views on the most desirable frequency for milk recording, reported that monthly tests are unreliable and that 21-day tests are permissible only where necessary. HERWEG considers the requirements of this author too stringent, and in order to support his views, he recorded the milk and fat yield of a cow for one lactation. The calculated yield/

yield on the basis of 14-, 21-, and 28-day tests were respectively 3229 Kg. (7120 lbs.), 3211 Kg. (7080 lbs.) and 3380 Kg. (7453 lbs.) of milk, and 111.798 Kg. (246.5 lbs.), 117.68 Kg. (259.4 lbs.), and 121.71 Kg. (268.3 lbs.) of fat. KERWEG points out that the differences between the calculated and the actual yield for the 14- and the 21-day tests are very slight. Finally he comes to the conclusion that in general 21-day milk and fat tests are adequate, as they give about the same results as the fortnightly tests. It does not seem justifiable, however, to rely upon a conclusion drawn from one individual case.

ECKLES (1912), basing his conclusions on experimental and observational evidence, pointed out the defect of short time tests. He stated that "tests of dairy cows made for short intervals at the beginning of the lactation period cannot be depended upon to indicate the normal percent of fat produced by the cow tested".

WENDT (1913), like KIRCHNER and ULLMANN, based his numerous investigations on data collected from the herd of the Agricultural Institute of the University of Leipzig. He compared the figures obtained by recording the milk, one, two, three or four times a month, once weekly or 6 times monthly with the actual yield for 15 cows. The test day was chosen in the middle of the test interval, and the actual yield of the experimental animals averaged about 2300 Kg. (5072 lbs.) of milk. The/

The maximum differences between the calculated and the actual yield, expressed in percentage of the latter were as follows:-

for 1-monthly tests, 7.32%, 2-monthly tests, 2.77%,

3-monthly tests, 2.33%, 4-monthly tests, 1.91%,

Weekly tests, 2.67%, and 6-monthly tests, 3.26%.

Thus the smallest maximum difference as well as the smallest average deviation was obtained in cases of four tests a month. This result was tested by the same author on 30 cows and it was found that 4-monthly tests showed only slight deviation from the actual performance, not exceeding 2.02%.

As regards the position of the test day, WENDT, on the basis of the weekly tests in 15 cows, established that the most accurate results were obtained when the test day lay in the middle of the test interval, while putting the test day at the beginning or at the end of the interval gave less accurate results in the same direction as indicated by KERCHNER in 1899. WENDT therefore refutes the view of ULLMANN, that a test day at the end of the interval gives the most accurate results, and points out that this method will give least accurate results for cows with a high yield.

In order to find out whether the milk yield has any influence upon the accuracy of the calculated yield, WENDT determined the deviation between the yield, as calculated/

calculated on the basis of 4-monthly tests, and the actual performance separately for cows giving more than 3000 Kg. of milk (6615 lbs.), and those giving less. He found that animals with a higher yield gave a relatively smaller maximum and average deviation than those with a lower yield.

It should be noted that WENDT'S conclusion concerning the influence of the yield upon the accuracy of the records cannot be regarded as reliable owing to the small number of cows used and to the statistical method employed. This conclusion, moreover, is not borne out by HOUSTON and HALE (q.v.).

Those observations on the accuracy of the weekly tests, made on 30 cows, were subsequently tested on a larger material involving 100 animals and confirmed, the greatest deviation from the actual yield being in the latter case 3.01%. Fortnightly tests gave a maximum deviation of 4.59% and WENDT considers this method of recording insufficiently accurate.

Finally WENDT concludes that though the results of weekly tests show a greater deviation from the actual yield than those for 4-monthly tests, the first system should be recommended for practical purposes, since the difference in the accuracy of the results is not sufficiently great to justify the greater technical difficulties involved in the second system. As to the fortnightly tests he believes that the method does not/

not give reliable results but because the high yielders showed a small deviation in the fortnightly tests, the maximum being only 2.85%, WENDT believes that in the case of high yielders, fortnightly testing will give quite satisfactory results.

KAEPPELI (1916), working on the herd of the Swiss Agricultural Experiment Station at Berne, obtained a total of 39 complete lactations in which the milk was recorded daily. The maximum deviation from the actual yield was found to be 2.94% for weekly records, 4.47% for twice monthly, and 4.69% for monthly. The actual lactation yield for the experimental animals averaged about 4000 Kg. (8820 lbs.) of milk.

From these results KAEPPELI concludes that both weekly and twice-monthly tests give results which are in close agreement with the actual yield, but that when the test is undertaken once a month, the deviation is considerably greater; consequently it is sufficient to carry out milk recording every second week. He assumes, without making any further investigations, that such a method will be sufficiently accurate for establishing the fat field as well.

HANSEN (1917) reported that his numerous observations had proved that recording milk twice a month or fortnightly is adequate for all practical purposes, as the results obtained are in sufficiently close agreement with the actual yield. He advises that longer

intervals/

intervals should, if possible, be avoided.

The methods of recording in the United States are quite different as regards frequency, from those in use in other countries. Such is the case with the 7-days test, which covers a period of 7 consecutive days and may be begun as early as the 7th day after calving. Such is also the case with the 30-days test, which is governed by the same rules as the 7-days test, but covers a period of 30 consecutive days. There is also in the United States the 7-days test 8 months (240 days) after calving. All these methods of recording are considered as official tests, while the semi-official test is one in which the test covers 2 consecutive days each month.

YAPP (1919) studied the relative accuracy of these systems with special reference to fat percentage and total fat yield. He found that the variability in the fat percentage is greater for the 7-days test than for the semi-official test and that the difference between these two systems is significant. The correlation between the 7-days and semi-official test was found to be very close both for milk and fat yield. In the 7-days test there was a greater difference in fat percentage between low and high yielders and a greater tendency for high percentage to accompany high fat production, than in the semi-official test.

Comparing/

Comparing the 7-days test with the 30-days test it was found that the former shows a higher fat percentage than the latter and the difference is most marked in the case of high yielders.

It should be noted, however, that in adopting the 7-days test two points should be taken into consideration. First, as the test may be begun as early as the 7th day after calving, the fat content obtained in this case may not represent the mean for the whole lactation period. Secondly, the result of such a test is not dependent on persistency of lactation.

As regards the 7-days test eight months after calving, YAPP found that this system gives a higher fat percentage in low fat yielders and a lower fat percentage in high fat yielders than the 7-days test. He believes that of all these systems the semi-official one represents most accurately the productive ability of cows.

In a further investigation a comparison was made between the results of one-day and 2-days test. The author recommends a test of 48 hours and believes that such a duration with a bi-monthly test gives completely satisfactory results.

GAERTNER (1921) studied the reliability of recording milk every 14, 21, 28 and 42 days, using the actual records of 50 cows from the herd of the Animal Breeding/

Breeding Institute at the University of Breslau, where milk was recorded daily for a complete lactation. When the maximum deviation from the actual yield was calculated it was found to be as follows:

14-day test, 171 Litres = 7% (377 lbs.);

21-day test, 624 Litres = 18% (1377 lbs.);

28-day test, 596 Litres = 23% (1315 lbs.);

42-day test, 840 Litres = 19% (1854 lbs.).

GAERTNER comes to the conclusion that recording milk at intervals longer than 14 days can give only very unreliable results, while a fortnightly test may be considered adequate in all cases except where particularly valuable breeding animals are concerned, in which case he recommends weekly test.

It is noted that the figures given by this author are relatively higher than those given by most of the other authors, and as the method by which the author calculated the yield according to different systems is not mentioned, such a great deviation and a high percentage of error cannot be accepted with entire satisfaction.

The work of REGAN and MEAD in 1921 is rather interesting as it brings out a somewhat different aspect. Discussing factors affecting the fat content of a cow's milk during a period of 2 days, they showed clearly to what extent the figures obtained by the recorder/

recorder could be influenced by the management of the herd. In their experiment the fat percentage could be increased during a period of two days (duration of semi-official test) by leaving half of the milk in the udder during the milking prior to the test; and although the average increase was only .27%, the data would seem to indicate that it is possible to obtain an increase of over 0.5%. They noticed that the highest fat percentage was not always reached at the milking following the partial milking; as out of the 27 trials there were 12 in which this was reached at the second milking. The authors added that such a practice of leaving some of the milk in the udder prior to the two-days test could not be detected by a study of the cow's milk record since there was an average increase of only 0.766 lbs. of milk for the period following the partial milking.

ERCHINGER (1923), assuming that it has been proved that the 14-day test gives results sufficiently accurate for practical purposes, only investigated the question of the relative accuracy of 14-day and 21-day tests. His material consisted of daily milk and fat records of 57 cows in two East Friesian herds in the course of one year. ERCHINGER calculated the yield on the basis of 14- and 21-day tests by adding up the yields of the test days and multiplying the result by 14 or 21. The deviation of the calculated yield from the actual was determined and the results are given in Table I.

TABLE 1.

Method of Recording	Value of Deviation		
	Milk yield	Fat %	Fat yield
14-day test	84 Kg. (185 lbs.)	0.050	4.0 Kg.(8.8 lbs.)
21-day test	96 Kg. (212 lbs.)	0.067	4.6 Kg.(10.1 lbs.)

The actual yield for the experimental animals averaged 4500 Kg. (9923 lbs.) of milk and 140 Kg. (309 lbs.) of fat. The author concludes from these results that "the prevailing view that the 21-day test is not sufficiently accurate is erroneous, and that this system differs only slightly from the 14-day test as regards accuracy while the superiority of the latter does not offset its greater cost". Further, ERCHINGER found that the calculated values for milk-yield always, and for fat yield in the majority of cases, lay above the actual yield, and believed that this can be explained by incorrect recording of the yield during the first period after calving. The errors concerning milk yield, fat content and fat yield arising from the method of recording, are, in ERCHINGER'S opinion, inversely proportional to the yield. This opinion is held by WENDT but is contradicted by HOUSTON AND HALE.

LAPLAUD/

LAPLAUD (1924) carried out an experiment in which a comparison was made of the actual milk and fat yields with those calculated from weekly, fortnightly, three-weekly and monthly tests. The material consisted of 10 pure-bred Normandy cows during the course of one lactation. A summary of the results of this experiment in which the greatest variation between calculated and actual yield is expressed as a percentage of the latter, is given in Table 2.

TABLE 2.

Method of Recording	Maximum Deviation in %	
	Milk yield	Fat yield
Weekly	3.5	4.3
Fortnightly	5.8	6.6
Three-Weekly	8.1	11.7
Monthly	9.9	9.9

It should be noted that these figures are under-estimated because LAPLAUD avoided the errors due to the variations at the beginning and end of the lactation by eliminating these periods in all the calculations.

This/

This point was given careful consideration by VOGEL in his study in 1932.

McCANDLISH and McVICAR (1925) studied the relative accuracy of the two methods of estimation that have been used by the Scottish Milk Recording Association, the "old" method which was used until the end of 1914, and the "new" method which has been in use since that time. The official instructions for applying the two methods are as follows:-

Old method. For the first test of a lactation multiply the total quantity of evening and morning milk for each cow by the number of days which have elapsed since the cow calved, and on the second and each succeeding test multiply the quantity of milk by the actual number of days which have elapsed since the last test.

New method. For the first test of lactation multiply the total quantity of evening and morning milk for each cow by the number of days which have elapsed since the cow calved, plus half the number of days in the average interval between tests. On the second and each succeeding test multiply the quantity of milk by the actual number of days which have elapsed between tests, thus regarding each day of test as the middle day of the period covered by the test.

In/

In addition to calculating the records at 10-day intervals, McCANDLISH and McVICAR calculated them by both methods at 20 and 30 days intervals, in order to determine the influence of the length of the interval between tests. The average yield of the 24 records studied is 642 gallons of milk (6441 lbs.); the results obtained from comparison of the yields calculated by different methods with the actual performance are shown in Table 3.

TABLE 3./

TABLE 3.

Method	Average yield	Variation from the average	Maximum Variation		Range of Variation.
			Increase	Decrease	
Old.	Gallons.	Gallons.	Gallons.	Gallons.	Gallons.
10-day	631 (6330 lbs.)	- 11 (110 lbs.)	9 (90 lbs.)	36 (361 lbs.)	45 (451 lbs.)
20-day	617 (6190 lbs.)	- 25 (251 lbs.)	...	65 (652 lbs.)	65 (652 lbs.)
30-day	594 (5859 lbs.)	- 48 (482 lbs.)	...	93 (933 lbs.)	93 (933 lbs.)
New.					
10-day	647 (6491 lbs.)	5 (50 lbs.)	24 (241 lbs.)	13 (130 lbs.)	37 (371 lbs.)
20-day	647 (6491 lbs.)	5 (50 lbs.)	25 (251 lbs.)	32 (321 lbs.)	57 (572 lbs.)
30-day	643 (6451 lbs.)	1 (10 lbs.)	46 (461 lbs.)	36 (361 lbs.)	82 (823 lbs.)

From this table it is evident that the new method of calculation is quite satisfactory, and gives a greater degree of accuracy than the old method. The authors draw attention to the important point that when the new method of calculation is used, about the same number of individual records show an increase or a decrease, while with the old method the chances are great that the calculated record will be less than the actual.

Finally McCANDLISH and McVICAR concluded that the new method of calculating milk yield at present used by the Scottish Milk Recording Association gives results which are in close agreement with the actual yield, and moreover it gives the cow an even chance while the old method puts her under a handicap. The suggested explanation is that with the old method of calculation, the length of the lactation period will, on the average, be shorter than the true lactation by a period approximately equal to half the interval between tests.

This investigation deserves great attention in view of the extensive use of the system in question, but the material employed is insufficient to give vonclusive results. The findings of these authors will be discussed at a later point in connection with the study of the Scottish Milk Recording System.

The study which was undertaken by SHEEHY of Ireland in 1926 is of great interest, as it deals with

6 short-cut methods of obtaining the lactation milk yield and 10 short-cut methods of estimating the total lactation fat yield. His data involved 8 cows: the milk of each was recorded daily and the fat percentage determined by analysing a composite morning and evening daily sample during the course of one lactation.

The errors resulting in the case of all cows tested according to any one short-cut method were considered collectively, and the maximum and average error associated with that method were expressed in a percentage of the actual yield. The results obtained in the case of milk yield are summarised in Table 4.

It will be noted from this table that when weekly weighings are adopted the results approximate very closely to the true figures and that as the length of the interval between weighings increases, the error also increases.

Dealing with fat yield and taking the recorded cows collectively, the maximum and average errors which occur when using different methods of testing are given in Table 5.

TABLE 4./

TABLE 4.

MILK YIELD.

Method Employed	Maximum Error %	Average Error %
Weighing one day's yield:		
At intervals of one week	+1.5 and -2.1	± 0.64
" " " two weeks	+3.0 " -4.3	± 1.44
" " " three "	+4.3 " -5.0	± 1.48
" " " four "	+5.4 " -5.8	± 2.37
" " " five "	+8.0 " -6.3	± 2.47
" " " six "	+6.0 " -8.2	± 3.08

It can be seen from this table that weekly tests give a result which approximates closely to the true figure, that the results obtained from fortnightly tests diverge further but not considerably more than those of weekly tests from the actual yield, and that those calculated from tests taken at intervals greater than a fortnight are liable to give single results which are to a serious extent above or below the correct figure. Testing on two consecutive days at long intervals, in SHEEHY'S opinion, does not give any better result than does the method of taking the same total number of tests collected at shorter intervals from single rather than from two consecutive days' samples. The results obtained/

than from two consecutive days' samples. The results obtained by the method of taking a small number of samples at random during the lactation may, in single instances, diverge to an alarming extent from the correct figure though the average error, even according to this method, remains a comparatively small figure.

TABLE 5.

FAT YIELD.

Method Employed	Maximum Error %	Average Error %
Testing one day's yield:		
At intervals of one week	+3.8 and - 3.3	± 1.40
" " " two weeks	+ 5.6 " - 4.9	± 2.60
" " " three "	+ 9.4 " - 9.8	± 2.88
" " " four "	+10.6 " -11.2	± 2.98
" " " five "	+10.7 " - 9.4	± 2.88
" " " six "	+11.6 " -12.1	± 3.16
Five times during lactation at nearly regular intervals	+12.1 " -14.2	± 3.85
Four times during lactation at irregular intervals	+14.7 " -18.1	± 4.64
Testing two consecutive day's yield		
At intervals of six weeks	+ 9.2 " - 9.6	± 2.88
At " " seven "	+ 9.0 " - 9.6	± 2.88

Finally, the author states that "where question of practicability demands longer intervals between the fat tests, it is advisable to record the milk weekly, because in the calculation for total fat yield the recorded milk yield figure is utilised, and it is important that the smallest possible error be thus introduced into the calculation.

Attention should be drawn to the limited number of cows available in SHEEHY'S study, and to the error introduced in calculating the total fat yield from the results of composite evening and morning samples instead of analysing them separately.

SAIZ (1927) has recommended a further system of recording known as the 6 - 5 - 8 method. This system consists in testing the cows during the 6th week, the 5th month and the 8th month after the beginning of the lactation, taking the average and multiplying it by the number of days in the lactation period. This system does not appear to have given very satisfactory results, for in the few cases in which it has been adopted it was abandoned and is practically no longer used. So far as we are aware no further studies have been made to test the accuracy of this system, and therefore it would not be advisable to recommend it.

The question of extending the interval between tests to two months has been discussed mainly in America/

America, where such a possibility would be of great importance for the milk recording movement, in view of the fact that the enormous distances have to be covered by the recorders in travelling from one farm to another which makes recording at short intervals costly. For this reason the possibility of extending the interval to 2 months is discussed almost exclusively by American workers.

McDOWELL (1927), working on the herd of the Minnesota Agricultural Experiment Station, investigated the reliability of testing cows every month and every second month. The material consisted of 70 cows, the daily milk and fat yields of which were recorded throughout one year. When calculating the performance according to the systems of recording in question, the test day was placed in the middle of the test interval.

When the 70 yearly individual cow records of fat production were figured on the basis of a one-day test every two months, the average variation from the actual expressed in percentage of the latter was 3.8%. In 24 cases out of the 70 studied, the error was 5% or more, while the greatest error for any one record was 12.5%.

When the same records were figured on the basis of a one-day test each month, the average variation from the actual yield was 2.91% and therefore the difference in average error between the two systems is approximately/

approximately 0.9%. The greatest error for a one-day test each month was 8.3%, the difference between the two systems being about 4.2%.

McDOWELL, basing his conclusion on this study and on results obtained in Virginia, believes that testing every two months, while not as accurate as testing every month, is yet sufficiently accurate for practical purposes. It should be noted that this investigation was restricted to fat production.

With reference to the study of YAPP in 1919 concerning the reliability of the so-called official tests, an objection has been raised against the 7-days test begun immediately after calving, namely, that the fat content obtained in this test may not represent the mean for the whole lactation. Another objection was that the result of this test is entirely independent of the form of the lactation curve.

GAINES (1927), investigating the accuracy of the different methods of recording mainly used in America, found that the former drawback could be avoided by deferring the fat test to 60 days after calving, while the latter could be avoided by deferring the test to the 5th month of lactation.

COPELAND (1928) selected at random 250 Register of Merit records made under monthly two-days supervision and 250 records under one-day supervision and computed the yearly fat records by using only the alternate regular/

regular tests. By comparing the results obtained from the bi-monthly tests with those of the monthly, the average variation was found to be 6.73 lbs. of fat = .90%; in the case of two-days supervision and 7.69 lbs. of fat = 1.53% in the case of one-day supervision.

In considering these results it may be noticed that records which are made every other month under supervision show little variation from those made under the usual monthly supervision.

GIFFORD (1930) also discusses this question, but compares the records of bi-monthly tests only with those of monthly tests. By comparing the records of the even months with the records for the odd months, he found in every case that there are only negligible differences and he concludes by recommending a bi-monthly test being as sufficiently accurate.

VOGEL (1931) studied the relative accuracy of recording milk and fat yields for 24 hours at intervals of 7, 14 and 21 days, and for 48 hours at intervals of 14 and 21 days. His data consisted of 15 cows with a total of 29 lactations, in the course of which milk and fat yields were recorded daily. The total lactation yield based on any of these systems was calculated by multiplying the amount recorded during the test period by the number of days in the test interval, and adding up all the figures for the test intercals falling within that lactation. For the sake of uniformity, the test period was in all cases taken in the middle of the test interval.

The range of variation of the calculated yield ($M \pm \sigma$) in the case of different systems expressed in percentage of the standard yield, is given in Table 6.

TABLE 6.

Test	Interval	Range of Variation	
		Milk	Fat
24 hours	7 days	97.07 - 104.68	93.96 - 107.02
	14 "	94.27 - 108.24	92.00 - 110.30
	21 "	93.10 - 109.28	90.23 - 113.07
48 hours	14 "	95.22 - 107.23	94.16 - 107.89
	21 "	94.74 - 108.21	92.99 - 110.13

By converting the percentages into absolute figures, on the assumption that 100 = 4000 Kg. (8820 lbs.) milk or 140 Kg. (309 lbs.) fat, the figures given in Table 7 are obtained.

In summarising his results, the author states that, since the reliability of recording is determined by the duration of the test and the length of the interval, the problem consists of selecting those conditions which give the best results and are at the same time practicable and not too costly. In his opinion a 24-hours test with 21 days interval answers both purposes.

TABLE 7.

Test Interval	Range of Variation Kg.		Maximum Difference	
	Milk	Fat	Milk	Fat
24 hrs. 7 days	3882.8 - 4187.2 (8562 lbs) (9233 lbs)	131.54 - 149.83 (290 lbs) (330 lbs)	304 (670 lbs)	18.29 (40.3 lbs)
14 "	3770.8 - 4329.6 (8315 lbs) (9547 lbs)	128.88 - 154.42 (284 lbs) (340 lbs)	559 (1233 lbs)	25.62 (56.5 lbs)
21 "	3724.0 - 4371.2 (8211 lbs) (9638 lbs)	126.32 - 158.30 (279 lbs) (349 lbs)	647 (1427 lbs)	31.98 (70.5 lbs)
48 hrs 14 "	3808.8 - 4289.2 (8398 lbs) (9458 lbs)	131.82 - 151.05 (291 lbs) (333 lbs)	480 (1058 lbs)	19.23 (42.4 lbs)
21 "	3789.6 - 4328.4 (8356 lbs) (9544 lbs)	130.19 - 154.18 (287 lbs) (340 lbs)	539 (1188 lbs)	23.99 52.9 lbs)

Attention should be given to VOGEL'S work as he is one of the few to analyse the results statistically.

BREIREM of Norway, published in 1931 a paper entitled "Milk recording, its significance, object and problems, accuracy of calculated yield" in which he reports on 71 lactations. With three tests a month the average deviation was 1%, with two tests a month, 1.4% and with monthly tests 2.4%. From these results he concludes that 21-day and even 28-day tests are sufficiently accurate for practical purposes, particularly in view of other sources of error.

As previously mentioned, ERCHINGER (1923) came to the conclusion that the difference between the calculated yield and the actual, in any system of recording, is largely due to an inexact determination of yield the first time after calving. In order to get a more exact appreciation of the reliability of milking tests at the beginning and the end of lactation, VOGEL (1932) determined for 20 lactations the difference between actual yield and that based on 14-day tests during the first 3 test periods after calving and the last one in the lactation. The methods of recording studied are:-

a. test day situated in the middle of the test interval
b. " " " at the beginning " " " "
c. " " " at the end " " " "

VOGEL concludes that the closest agreement of calculated/

calculated and actual yield of both milk and fat is obtained with the application of method (a), a higher calculated than actual yield with (b), and a lower calculated than actual yield with method (c).

In a further investigation the same author studied the reliability of calculating the total lactation with 14-day test periods and different methods of calculation, namely (a), (b), (c), (as mentioned above); (d) the average was taken of the yield of all test days of each lactation and multiplied by milking days of the corresponding lactation; and (e) this average was at first multiplied by 14 to give the average for a 14-day test period, and these averages multiplied by the number of test periods of the corresponding lactation.

It was found that the deviation of the calculated milk yield from the actual was on the average smallest with methods (a) and (e); for fat yield the result was similar, but the calculated values for both methods generally lie a little higher than for milk yield. The only disadvantage of using method (e) is that yield can be calculated only after all the results for the corresponding lactation are available, while with method (a) calculation can be done for every test period immediately after the test has been done.

HOUSTON and HALE (1932) reported that dealing with milk yield it was found that the error in the weekly test results was in only one case out of 20 cases/

cases studied above 2.5% of the actual performance. Consequently, weekly weighings may be considered as an established practice and to give results which agree closely with the actual figures. As to the fortnightly weighings of milk, the authors are of the opinion that a certain amount of accuracy is sacrificed by adopting this system.

In the second part of this investigation, the total fat yield was calculated from tests taken at intervals of 1, 2,3,4,6 and 8 weeks, and when the results obtained were compared with the actual yield, the maximum errors were found to be respectively, 3.13, 5.09, 6.05, 9.92, 12.41, and 12.79% of the actual. Thus in order to ensure that the error in the calculated fat yield does not exceed 10% of the actual, the interval between tests should not be longer than one month.

An interesting part of this study deals with the correlation between the total milk yield and the standard deviation of the record. Contrary to WENDT and his supporters, HOUSTON and HALE believe that there is no correlation between the yield and the error. This conclusion, however, is not based on a significant statistical analysis.

SOLOVJEV published in 1933 a paper on methods of determining fat yield. In his opinion, the most accurate/

accurate results concerning fat percentage and fat yield, hardly differing from those obtained by daily measurements, are obtained with 10-day tests during the course of the whole lactation. Tests at intervals of not more than 30 days would give a comparatively accurate picture of fat yield, while tests carried out only 3 - 4 times during the entire lactation would be misleading.

HUBER and BIERI, in Switzerland, found from observations on 20 cows, a difference of 129 Kg. (284 lbs.) per cow per year (or 3.6%) between the daily yield and the results of fortnightly tests; the difference is considered insignificant.

Reference should be made to the study of milk recording methods which was undertaken by TAUSSIG in 1934. The author analysed and compared the results of different writers, and so far as we are aware he has done no original work on the subject.

While it is very desirable to have a record for a complete lactation, and consequently the majority of writers have paid great attention to this point, there are times when it may be desired to estimate the performance from an incomplete milking period. To meet this condition, GORDON of Wisconsin Farm has compiled a table which was calculated from records taken daily. It should be borne in mind that at best such a table is/

is only an approximation. The only reason for a table of this kind is to permit a quick estimate to be made of the probable production of a heifer in a case of emergency when complete records are not available.

RINGLER (1937), using VOGEL'S method, investigated the accuracy of recording milk and fat yields for 24 hours at intervals of 7,14,21 and 28 days, and for 48 hours at intervals of 14, 21 and 28 days. His data consisted of 37 cows with a total of 58 lactations, in the course of which milk and fat yields were recorded daily. The test period was always taken in the middle of the test interval and great care was observed in calculating the yield of the first and last interval in the lactation.

RINGLER analysed the data statistically and the values of σ are shown in Table 8, where are given also the values for the arithmetic mean M, as well as the range of true mean obtained from the formula $M \pm 3\sigma$, and finally the range of variation derived from these.

TABLE 8./

TABLE 8.

Duration of test hours.	Test interval. Days	σ	3σ	Mean	$M \pm 3\sigma$	Range of Variation
			Milk	yield		
24	7	1.0017	3.0051	100.0058	97.0007-103.0109	6.0102
24	14	1.8796	5.6388	100.2075	94.5687-105.8463	11.2776
24	21	2.1140	6.3420	101.1324	94.7904-107.4744	12.6840
24	28	2.1974	6.5922	100.4646	93.8724-107.0568	13.1844
48	14	1.1799	3.5397	99.9063	96.3666-103.4460	7.0794
48	21	1.6426	4.9278	100.7515	95.8237-105.6793	9.8556
48	28	1.7800	5.3400	100.3152	94.9752-105.6552	10.6800
			Fat	yield		
24	7	1.6097	4.8291	100.3045	95.4754-105.1336	9.6582
24	14	2.5120	7.5360	100.7232	93.1872-108.2592	15.0720
24	21	3.3267	9.9801	101.3310	91.3509-111.3111	19.9602
24	28	3.2982	9.8946	100.2704	90.3758-110.1650	19.8946
48	14	1.6798	5.0394	99.7183	94.6789-104.7577	10.0788
48	21	2.2571	6.7713	100.7980	94.0267-107.5693	13.5426
48	28	2.4356	7.3068	100.1192	92.8124-107.4260	14.6136

If the actual yield for a lactation be taken as 4000 Kg. (8820 lbs.) of milk and 152 Kg. (335 lbs.) of fat (figures which correspond to the actual average of the 58 lactations investigated) the limits and ranges of variations will be obtained as in Table 9.

TABLE 9.

It will be observed from Tables 8 and 9 that the calculation of fat yield shows greater deviation from actual performance than that of milk yield. The differences between the limits of 21-day and 28-day tests with a 24-hour test are insignificant, or at any rate very much smaller than those between the 7-day and 14-day test; similarly with a 48-hour test, the differences between the 21-day and 28-day intervals are smaller than those between 14- and 21-day intervals.

Finally, the author concludes that 24-hour tests at 28-day intervals are as satisfactory as the same tests at 21-day intervals - a conclusion which confirms that of BREIREM.

From a study of the papers reviewed and consideration of the findings of the various authors, it is apparent that there is marked difference of opinion. The majority express views and opinions which are undoubtedly mainly correct, but the value of many is reduced owing to the fact that there is insufficient scientific evidence to prove their accuracy. In only a very few cases was the experimental material sufficiently large, and it is rather hazardous to draw conclusions/

TABLE 9.

I. MILK YIELD.

Range of Variation.

(a) 24-hour tests.

Every 7-days	3880.00 Kg.	(8555 lbs.)	-	4120.44 Kg.	(9086 lbs.)	=	240.44 Kg.	(530 lbs.)
" 14 "	3782.75 "	(8341 ")	-	4233.85 "	(9336 ")	=	451.10 "	(995 ")
" 21 "	3791.62 "	(8361 ")	-	4298.98 "	(9479 ")	=	507.36 "	(1119 ")
" 28 "	3754.90 "	(8280 ")	-	4282.27 "	(9442 ")	=	527.37 "	(1163 ")

(b) 48-hour tests.

Every 14 days	3854.66 Kg.	(8500 lbs.)	-	4137.84 Kg.	(9124 lbs.)	=	283.18 Kg.	(624 lbs.)
" 21 "	3832.95 "	(8452 ")	-	4227.17 "	(9321 ")	=	394.22 "	(869 ")
" 28 "	3799.01 "	(8377 ")	-	4226.21 "	(9319 ")	=	427.20 "	(942 ")

II. FAT YIELD.

(a) 24-hour tests.

Every 7 days	145.12 Kg.	(320.0 lbs.)	-	159.80 Kg.	(352.4 lbs.)	=	14.68 Kg.	(32.4 lbs.)
" 14 "	141.64 "	(312.3 ")	-	164.55 "	(362.8 ")	=	22.91 "	(50.5 ")
" 21 "	138.85 "	(306.2 ")	-	169.19 "	(373.1 ")	=	30.34 "	(66.9 ")
" 28 "	137.37 "	(302.9 ")	-	167.45 "	(369.2 ")	=	30.08 "	(66.3 ")

(b) 48-hour test.

Every 14 days	143.91 Kg.	(317.3 lbs.)	-	159.23 Kg.	(351.1 lbs.)	=	15.32 Kg.	(33.8 lbs.)
" 21 "	142.92 "	(315.1 ")	-	163.50 "	(360.5 ")	=	20.58 "	(45.4 ")
" 28 "	141.07 "	(311.1 ")	-	163.29 "	(360.1 ")	=	22.22 "	(49.0 ")

conclusions from observations on single or even small populations of six or ten cows, as is the case in the literature.

Several investigators err in the method of analysing the data. It is insufficient to calculate the simple arithmetic mean, as two similar arithmetic means may be calculated in very different ways. It is particularly important to consider the variation of the deviation of the calculated yield from the actual, and useful results can only be obtained with the aid of comprehensive statistical analysis.

It is thus obvious that a study of the reliability and relative accuracy of different systems of milk recording as determined from an adequate statistical analysis of exact and sufficient data is urgently needed as it will play an important part in the development of milk-recording schemes and consequently aid in selection, progeny test work, and in the general genetical improvement of cattle.

THE OBJECTS OF THE PRESENT INVESTIGATION.

In this paper our concern is to determine the reliability of different systems of recording in general, and of two systems in particular which cover

a/

a large body of data, dealing with milk yield and fat yield separately:

Section I. The relative accuracy of recording milk and fat yields weekly and at intervals of two, three and four weeks.

Section II. The accuracy of the system of recording adopted by the Scottish Milk Recording Societies.

Section III. The reliability of the system of recording used in England and Wales.

EXPERIMENTAL MATERIAL.

The data for the present investigation were derived from the records of the Experimental Farms, Cockburn and Shothead. In the hope of eliminating the influence of all factors but those studied, the investigation was restricted to these two farms which are under the same management and are situated in the same district, so that the environmental conditions, methods of feeding, and general husbandry are almost identical. Furthermore, it was desirable that the cows considered should all be of one breed in order to eliminate any breed differences. The breed selected was the Ayrshire, as it is one of the major dairy breeds in Scotland, England and Wales. A brief description should be given of the methods of recording at these two farms.

Milk. Cows are milked at equal intervals and the milk is weighed at each milking. The results, which are recorded daily in the byre book, are totalled at the end of each week and transferred to the yearly records. At the end of the lactation period the total yield is determined by adding up the weekly figures. Thus, as far as milk yield is concerned, the farms' records give the actual performance.

Fat. Samples of milk are taken for each cow once a week/

week. The morning and evening samples are tested separately for percentage of milk fat by the Gerber method and the average percentage of these two samples is taken to represent the week in question, regarding the test day as falling in the middle of the test interval. From the average fat percentage and the actual milk yield for the week, the fat yield for the week is calculated. At the end of the lactation the total fat yield is determined by adding up the weekly figures. Therefore the fat yield as taken from the farms' records is derived from weekly tests for fat percentage and the actual milk yield. It will be seen that this system gives figures in close agreement with the actual performance.

PRELIMINARY STUDY: THE RELIABILITY OF THE FARMS' RECORDS.

The method adopted at the farms of calculating the fat yield appears to be unique and, so far as the writer is aware, its reliability has never been tested. Owing to the fact that in most of our studies the figures taken from the farms' records form the basis of comparison for the results given by different systems of recording, it is desirable to determine their accuracy.

For this purpose a number of cows were selected, including individuals at different stages of lactation and with high and low fat yields. Milk was analysed by/

by the author for each cow at each milking separately during the course of one week. From the fat percentage and the milk yield for each milking the fat yield in pounds was determined. At the end of the week the actual fat yield was obtained by totalling all the figures representing the milkings which fell within that week. These figures were taken as a basis of comparison with those calculated by the method in use at the farms. The experiment lasted for 8 weeks and 201 cases were investigated.

The mean actual yield of fat per week, for all the cows involved is 8.706 lbs. while that calculated by the farms' method is 8.641 lbs. This shows that the method used by the farms gives, on the average, a value which is .065 lbs. of fat less than the actual figure. The results of the statistical analysis of the data are given in Table 10.

TABLE 10. /

TABLE 10.

Statistical Analysis of Data for fat yield calculated by the Farms' method.

		Value	±	standard error
Mean actual yield	lbs.	8.706	±	.1540
Mean error (difference between the actual and the recorded)	lbs.	-.065	±	.0497
Standard deviation of the actual yield	lbs.	3.087	±	.1540
Standard deviation of the error	lbs.	.7048	±	.0035
Maximum error (increase)	lbs.	2.5		
Maximum error (decrease)	lbs.	2.2		
Range of variation	lbs.	4.7		
Correlation coefficient between the actual yield and the error		-.013	±	.071
Regression coefficient of the error on the actual yield		-.003		

From this table it is evident, that the error involved in the farms' records is on the average 0.75% of the actual weekly yield, which indicates a high degree of accuracy. Taking into account that 95% of the variates will fall within the range of the mean ± twice the standard deviation, the range of variation of the calculated weekly yield will be from 7.23 lbs. to 10.05 lbs. of fat.

The correlation coefficient between the actual yield and the difference is insignificant as its value is even less than its standard error. As may be observed from the negative correlation, and also from a study of the individual records, there is a tendency for the error to decrease as the fat yield increases, but the value of the regression coefficient is so small that such difference in the mean error can be considered negligible.

Thus while the records of the farms concerned give the actual yield as regards milk, it may be concluded that the manner of calculating the fat yield gives sufficiently accurate and reliable results to justify the use of the figures derived from these records in a criticism of other methods.

It should be noted that this error is not merely the error of weekly as compared to daily estimations of fat yields, but includes also the error of analysis of the sample on the part of the recorder. In this connection, it should be noted that every reasonable precaution/

precaution is adopted to ensure that the samples tested are of the right temperature. As it was realised that on this point lay the possibility of error, special precautions were adopted to ensure accuracy in the estimations of the daily test, and no special precautions, beyond the usual routine, were adopted by the farm recorders.

SECTION I.

THE RELATIVE ACCURACY OF RECORDING MILK AND FAT YIELDS WEEKLY AND AT INTERVALS OF TWO, THREE AND FOUR WEEKS.

In this section a total of 202 completely normal lactations were obtained, and great care was taken to eliminate those in which there was any illness or a period during which the yield was estimated or missed.

TREATMENT OF MATERIAL.

From the farms' records the actual milk yield during a lactation, and the fat yield calculated by the method previously described, were obtained for each cow. These figures were compared with the values calculated from tests at intervals of 7,14,21 and 28 days. The test was always taken on a Tuesday and the first test day was the first Tuesday after the day of calving, provided it did not fall on one of the first three days of lactation, as it is well known that the yield of the cow during the first days after calving is very variable both as regards quantity and fat content. In such cases, and also when calving, and consequently the beginning of lactation, fell on a Tuesday, the first test day was on the following Tuesday and obviously in these cases the first test interval/

interval was a few days longer. Example. A cow calved on Monday, March 8, 1937; the first Tuesday after calving was the following day March 9, 1937. For reasons mentioned above, the first three days of lactation were not taken into consideration and the first test day was Tuesday, March 16, 1937; the test interval is in this case extended to 9 days. In another case the first test interval may be reduced. Example. A cow calved on Friday, January 1, 1937; the first three days of lactation are not considered and the first test day fell on Tuesday, January 5, so that the first test interval is only 5 days instead of 7. The last test day was the last Tuesday before going dry and in this case also it sometimes occurred that the last interval was either prolonged or reduced. Example. A cow went dry on Monday, September 20, 1937; the last test day was the previous Tuesday - September 14; and the 7-day interval is prolonged to 10 days.

In this way the inaccuracies due to the inexact determination of the performance at the beginning and the end of the lactation and to the failure of estimating separately the length of the first and the last test intervals were undoubtedly eliminated.

Position of test day.

The test day was always taken in the middle of the/

the test interval, as it is the usual practice in milk recording. The majority of writers who have investigated the influence of the position of the test day in the test interval have come to the conclusion that the best agreement between the recorded and the actual yield is obtained when the test day falls in the middle of the test interval. The results of the tests, therefore, extended over the following periods:

(a) for 7-days intervals: 3 days before the test + the test day + 3 days after the test
(3 + 1 + 3 = 7).

(b) for 14-days intervals: 6 days before the test + the test day + 7 days after the test
(6 + 1 + 7 = 14).

(c) for 21-days intervals: 10 days before the test + the test day + 10 days after the test
(10 + 1 + 10 = 21).

(d) for 28 days intervals: 13 days before the test + the test day + 14 days after the test
(13 + 1 + 14 = 28).

The milk and fat yields calculated by these methods were compared with the actual performance and the results analysed statistically in order to determine their relative accuracy. (In the case of fat yield the 7-day test figures were taken as the basis.)

RESULTS AND DISCUSSION.

MILK YIELD

The total lactation yield, based on any of the systems studied, was calculated by multiplying the yield on the test day by the number of days in the test interval and adding up all the figures for the test intervals falling within that lactation.
Table 11 gives the distribution of the 202 lactations involved according to the results obtained by the different methods of recording, in addition to the distribution of the actual figures as taken from the farms' records. It may be observed from the table that there exists no significant difference between the various distributions. This may be attributed to the fact that in none of these methods of recording is there a tendency for the calculated yield to be consistently either above or below the actual performance/

TABLE 11.

Table 11.

The Distribution of the Lactation Milk Yield calculated by the Different Methods.

	Number of Lactations.									
Lactation yield in lbs.	2000 - 4000	4000 - 6000	6000 - 8000	8000 - 10000	10000 - 12000	12000 - 14000	14000 - 16000	16000 - 18000	18000 - 20000	Total
Actual	0	7	54	72	44	16	7	2	0	202
7-day test	0	7	52	75	45	12	9	1	1	202
14-day test	0	5	56	75	41	15	8	1	1	202
21-day test	0	6	56	71	45	15	7	1	1	202
28-day test	0	7	55	71	46	13	8	2	0	202

performance. Further evidence of this is apparent from a study of the individual records, from which the following observations were made:

1. 7-day test - in 130 cases the calculated yield was above and in 72 cases below the actual.

2. 14-day test - in 119 cases the calculated records exceeded the actual performance and in 83 cases they were below.

3. 21-day test - in 111 cases the yield was underestimated and in 91 cases overestimated.

4. 28-day test - 89 calculated records were above and the other 113 records were below the actual values.

The difference between the calculated and the actual yield was determined separately for each invidivual for each method of recording, and these individuals were subsequently classified according to the deviation. The distributions obtained are given in Table 12. It shows that the longer the interval between tests, the greater the number of records falling in the groups of high deviations and the smaller the number falling in the low deviation groups. This applies whether the deviation is above or below the actual yield. Moreover, it is evident that the range of/

of variation increases with an increase and decreases with a decrease in the length of the test interval. This point may be further illustrated by a comparison of the distribution curves drawn on the same scale as given in Fig.1. The frequency polygons, shown in this figure, represent four distributions containing the same number of variates. They are quite different as regards the degree of variability.

The deviation of the calculated yield was also expressed as a percentage of the actual for each cow with reference to each of the four methods. The frequency distribution for each method is given in Table 13, which indicates the same results as drawn from Table 12.

TABLE 12./

TABLE 12.

The Distribution of the Absolute Error in Milk Yield Calculated by the Different Methods.

Deviation in lbs.		7-day	14-day	21-day	28-day
+	500-600	0	0	1	0
	400-500	0	1	2	1
	300-400	0	4	6	11
	200-300	2	14	8	17
	100-200	38	26	32	18
	0-100	90	74	42	42
−	0-100	63	54	59	46
	100-200	8	25	32	34
	200-300	1	4	14	23
	300-400	0	0	3	6
	400-500	0	0	2	3
	500-600	0	0	1	1
TOTAL		202	202	202	202

Fig.1. Distribution of the error in milk yield calculated by the different methods.

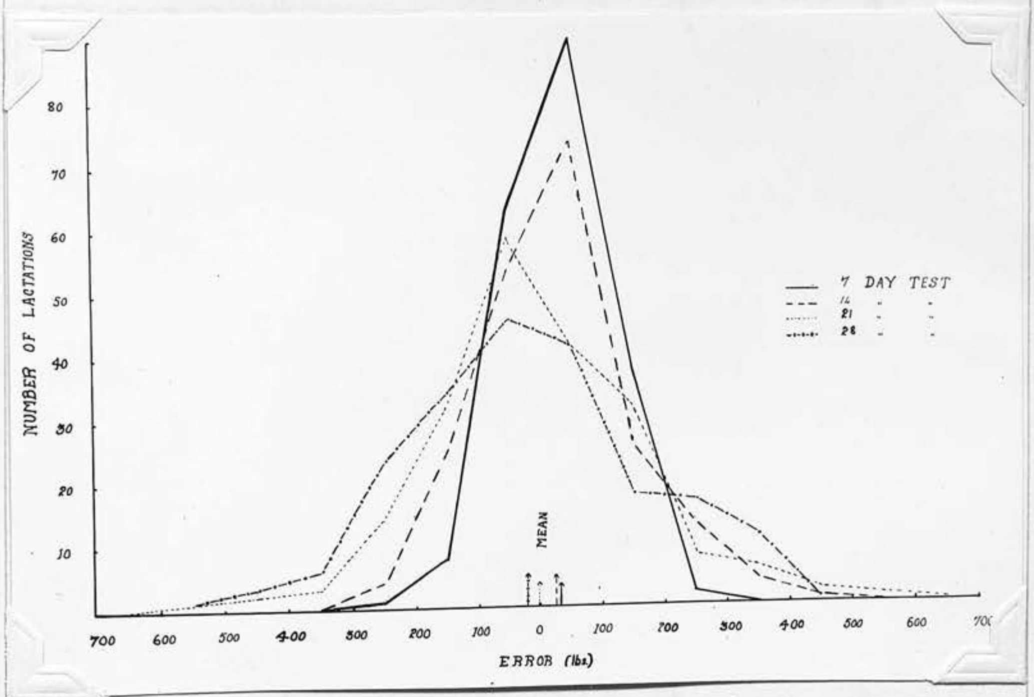


TABLE 13.

The Distribution of Percentage Error in Milk Yield calculated by the Different Methods.

	Percentage deviated	7-day	14-day	21-day	28-day
+	5 - 6	-	-	1	1
+	4 - 5	-	3	5	4
+	3 - 4	-	4	6	9
+	2 - 3	5	13	13	14
+	1 - 2	40	36	27	24
+	0 - 1	85	63	39	37
-	0 - 1	62	49	54	41
-	1 - 2	9	26	29	30
-	2 - 3	1	8	17	28
-	3 - 4	-	-	7	9
-	4 - 5	-	-	2	3
-	5 - 6	-	-	2	2
	TOTAL	202	202	202	202

Statistical Analysis of the Data.

The next step was to analyse statistically the data obtained, in order to determine the degree of probability that the results may be taken as an expression of the reliability of calculating yield under the same conditions and with the same methods. In the first place, the value of the standard deviation was calculated for the different variates in the case of each method. These values are shown in Table 14, along with the values for the arithmetic means and the range of variation obtained by adding the maximum error above and that below the actual yield. It should be borne in mind that the maximum errors referred to here are not in fact the maximum possible but only the greatest occurring in one individual record.

Taking into consideration that any variate lies with a probability of 95% within the range of the mean $\pm$ twice the standard deviation, we may assume that practically all estimates lie within this range. All values of $M \pm 2\sigma$, given in Table 15, demonstrate the limits within which the yields calculated by the different/

TABLE 14./

TABLE 14.

Statistical Analysis of Data for Milk Yield recorded by the Different Methods.

		7-day test	14-day test	21-day test	28-day test
Mean actual yield	lbs.	9345.32 ± 163.76	9345.32 ± 163.76	9345.32 ± 163.76	9345.32 ± 163.[illegible]
Mean error (recorded-actual)	lbs.	+32.03 ± 5.27	+25.39 ± 8.31	- 1.71 ± 11.95	-21.25 ± 13.[illegible]
Standard deviation of the actual yield	lbs.	2327.3 ± 115.79	2327.3 ± 115.79	2327.3 ± 115.79	2327.3 ± 115.[illegible]
Standard deviation of the error	lbs.	74.96 ± 3.73	118.10 ± 5.88	169.80 ± 8.45	185.10 ± 9.[illegible]
Maximum error (increase)	lbs.	234	425	525	414
Maximum error (decrease)	lbs.	210	277	563	542
Range of variation	lbs.	444	702	1088	956
Maximum % of error (increase)		2.52	4.25	5.03	5.65
Maximum % of error (decrease)		2.45	2.69	6.00	5.40
Range of variation in %		4.97	6.94	11.03	11.05

TABLE 15.

Absolute Variation of Milk Yield Recorded by the Different Methods.

Test	σ	2σ	Mean	$M \pm 2\sigma$	Range of Variation
7-day	74.96	149.92	9377.36 lbs.	9227.44 lbs - 9527.28 lbs.	299.84 lbs.
14-day	118.10	236.20	9370.71 "	9134.51 " - 9606.91 "	472.40 "
21-day	169.80	339.60	9343.61 "	9004.01 " - 9683.21 "	679.20 "
28-day	185.10	370.20	9324.07 "	8953.87 " - 9694.27 "	740.40 "

different methods and under the present circumstances vary about the mean, or in other words deviate from the actual yield.

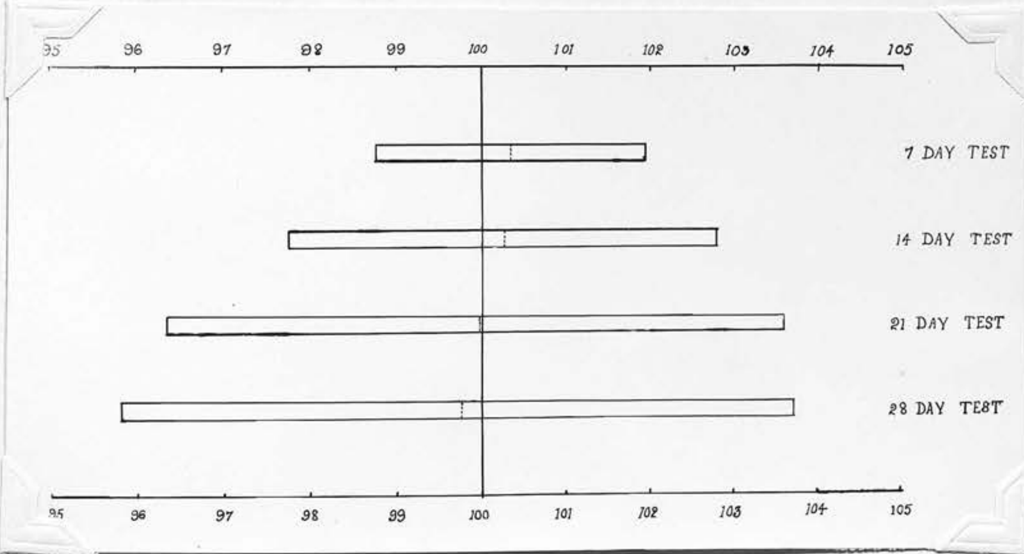
It may be deduced from these two tables that when tests are made at intervals of 7- and 14 days the calculated performance is higher than the actual, while with the 21 and 28-day tests the calculated yield is slightly below the actual. With the increase of the test interval, the range of variation increases and consequently the reliability of the method decreases. The difference between the limits of variation of the 21-day and 28-day tests is insignificant, or at any rate very much smaller than those between the 7- and 14-day tests, or between the 14- and 21-day tests. This is in agreement with the findings of GAERTNER (1921), VOGEL, (1931), and RINGLER (1937). In order to facilitate comparison with the results of these workers, the present data have been presented in accordance with the method recommended by JOHANNSEN and used by them, namely by taking 9345.32 lbs., which is the actual average of the 202 lactations investigated, as 100, and determining the relative limits and ranges of variation. These figures are given in Table 16 and graphically interpreted in Fig. 2.

TABLE 16.

Relative Variation of Milk Yield Recorded by the Different Methods.

Test	σ	2σ	Mean	$M \pm 2\sigma$	Range of Variation
7-day	.8021	1.6042	100.3428	98.7386 - 101.9470	3.2084
14-day	1.2637	2.5274	100.2717	97.7443 - 102.7991	5.0548
21-day	1.8170	3.6340	99.9817	96.3477 - 103.6157	7.2680
28-day	1.9807	3.9614	99.7726	95.8112 - 103.7340	7.9228

Fig.2. Graphic representation of M $\pm$ 2σ , i.e. the range of variation in milk yield calculated by the different methods.



The accuracy of the recorded yield as affected by the size of the yield.

In the course of the investigations, attention was also paid to the question of how far the amount of the actual yield influences the accuracy of the calculated figures. Different authors, such as WENDT (1913), ERCHINGER (1923) and RINGLER (1937), have expressed the opinion that the error involved in the system of recording is inversely proportional to the yield, while HOUSTON and HALE (1932) found no correlation between the actual performance and the error of the calculated figure.

In view of the diversity of opinion on this subject, and of the fact that as yet no conclusions have been drawn from adequate and comprehensively analysed data, the author deemed it advisable to carry out a full statistical study of this point. The correlation coefficient between the actual yield and the error was calculated, and in order to define the relation between the two variates in quantitative terms, the regression coefficient of the error on the yield was determined. The values for both the correlation and the regression in respect of each method are given in Table 17.

TABLE 17.

Correlation between Milk Yield and Error.

	7-day	14-day	21-day	28-day
Correlation Coefficient	+ .180 ± .068	+ .099 ± .070	+ .088 ± .070	+.015 ± .071
Regression Coefficient	+ .0058	+ .0050	+ .0064	+ .0012

It will be observed that there exists a positive correlation between the yield and the error in that the error increases with the increase in yield and decreases with the fall in yield. In each case, however, the value is less than three times its standard error and so can be regarded as insignificant. As regards the regression coefficient, the values are very low and insignificant as is apparent from the fact that for a variation in the yield of 1000 lbs., the deviation from the mean error is 6 lbs. in the extreme cases.

From this study it can be stated confidently that the error is almost independent of the yield. Such a conclusion was to be expected if we take into account that the accuracy of any calculated yield depends largely on the points discussed at the beginning of the paper (cf. P. 2).

FAT YIELD.

For fat yield the investigations were carried out in the same manner as for milk yield. The figures calculated from tests made at 7-day intervals were taken as the basis to determine the accuracy of the 14-, 21-, and 28-day tests. As it will be seen, the 7-day test gives figures which are in close agreement with the farms' records and gives a high degree of accuracy. This test has been used in preference to the farms' method in order to make the work comparable with other studies.

The reliability of the 7-day tests.

For the determination of the accuracy of this method, the milk of 201 cows was analysed by the author daily during the course of one week. The actual fat yield was compared with the calculated weekly yield, obtained by multiplying the yield on the test day by 7. The test day was taken in the middle of the test interval (3 + 1 + 3).

The actual weekly yield of the experimental animals averages 8.706 lbs. of fat and the mean difference between the weekly test figures and the actual performance is + .048. The data were analysed statistically and the results obtained are given in Table 18.

TABLE 18.

Statistical Analysis of Data for Fat Yield recorded weekly.

		Value $\pm$ standard error
Mean actual weekly yield	lbs.	$8.7056 \pm .1540$
Mean error (difference between the actual and the recorded)	lbs.	$+.048 \pm .0557$
Standard deviation of the actual yield	lbs.	$3.087 \pm .1540$
Standard deviation of the error	lbs.	$.7856 \pm .0039$
Maximum error (increase)	lbs.	4.1
Maximum error (decrease)	lbs.	2.7
Range of variation		6.8
Correlation Coefficient between the actual yield and the error		$+.061 \pm .070$
Regression coefficient of the error on the actual yield		+.0156

It is observed that the error involved in the weekly tests is on the average 0.55% of the actual yield. The range of variation for the calculated yield is from 7.18 lbs. to 10.33 lbs. ($M \pm 2\sigma$).

The correlation coefficient between the yield and the difference indicates that with the increase of yield there is an increase in the error, but such difference in the mean error is negligible as the regression coefficient is insignificant and the correlation is less than three times its standard error.

It is concluded that the weekly test gives accurate and very reliable results which can be safely used in determining the relative accuracy of other methods.

<u>The reliability of 14-, 21- and 28-day tests.</u>

The total fat yield in the course of each lactation was calculated separately for each of the three systems and the frequency distributions of the 201 records studied are given in Table 19, in addition to the distribution of the 7-day test figures.

It is apparent that the distributions are almost normal and the number of lactations in each group is much the same in the four cases.

A/

TABLE 19.

The Distribution of Lactation Fat Yield calculated by the Different Methods.

	Number of Lactations.										
Lactation yield in lbs.	150 - 200	200 - 250	250 - 300	300 - 350	350 - 400	400 - 450	450 - 500	500 - 550	550 - 600	600 - 650	Total
7-day test	0	20	38	44	46	31	8	10	3	1	201
14-day test	0	18	41	45	44	29	11	10	1	2	201
21-day test	0	21	33	48	42	34	11	9	1	2	201
28-day test	0	19	40	46	42	31	11	9	2	1	201

A study of the individual records was carried out for the purpose of finding out whether the calculated yield in 14-, 21-, and 28 day tests tends to fall above or below the figures based on the 7-day test. It was found that:-

1. 14-day test - in 83 lactations the calculated yield was over the 7-day test figures, 99 cases below and 19 the same.

2. 21-day test - in 90 lactations the calculated yield was over the 7-day test figures, 104 cases below, and 7 the same.

3. 28-day test - in 77 lactations the calculated yield was above the 7-day test figures, 116 cases below and 8 the same.

It may be noticed that the general tendency in the three systems is to give figures below those of the 7-day test and that this tendency increases as the test interval is prolonged.

The deviation of the calculated yield based on 14-, 21- and 28-day tests from the 7-day test figures was determined for each case and the 201 records studied were divided into classes with a range of 5 lbs. The results obtained are given in Table 20. As in the case of milk yield, the range of variation becomes wider as the test interval is prolonged, and hence there/

TABLE 20.

The Distribution of the Absolute Error in Fat Yield calculated by the Different Methods.

Deviation in lbs.		14-day	21-day	28-day
+	35 - 40	0	1	0
	30 - 35	0	1	2
	25 - 30	0	1	2
	20 - 25	0	2	2
	15 - 20	1	4	10
	10 - 15	12	18	11
	5 - 10	33	32	27
	0 - 5	56	38	31
-	0 - 5	49	33	31
	5 - 10	38	36	39
	10 - 15	7	19	21
	15 - 20	5	7	16
	20 - 25	0	5	4
	25 - 30	0	3	4
	30 - 35	0	1	1
TOTAL		201	201	201

there is a larger number of cases in the high deviation classes. Also it is noticed that the distributions in the case of 21- and 28-day tests are almost similar while there is a significant difference between the 14- and 21-day tests. These distributions are given in the form of frequency polygons on Fig.3. The curves show a tendency to flatten out with the increase of the test intervals. A great similarity could be observed between the 21- and 28-day tests as regards the general shape of their curves.

The deviation was also expressed as a percentage of the 7-day test figures, and Table 21 was compiled in the same way as Table 20. It will be noted that similar conclusions can be drawn. Also the calculation of fat yield shows greater deviation than that of milk yield. This is probably due to the additional source of error involved in estimating the butterfat percentage.

Fig.3. Distribution of the error in fat yield calculated by the different methods.

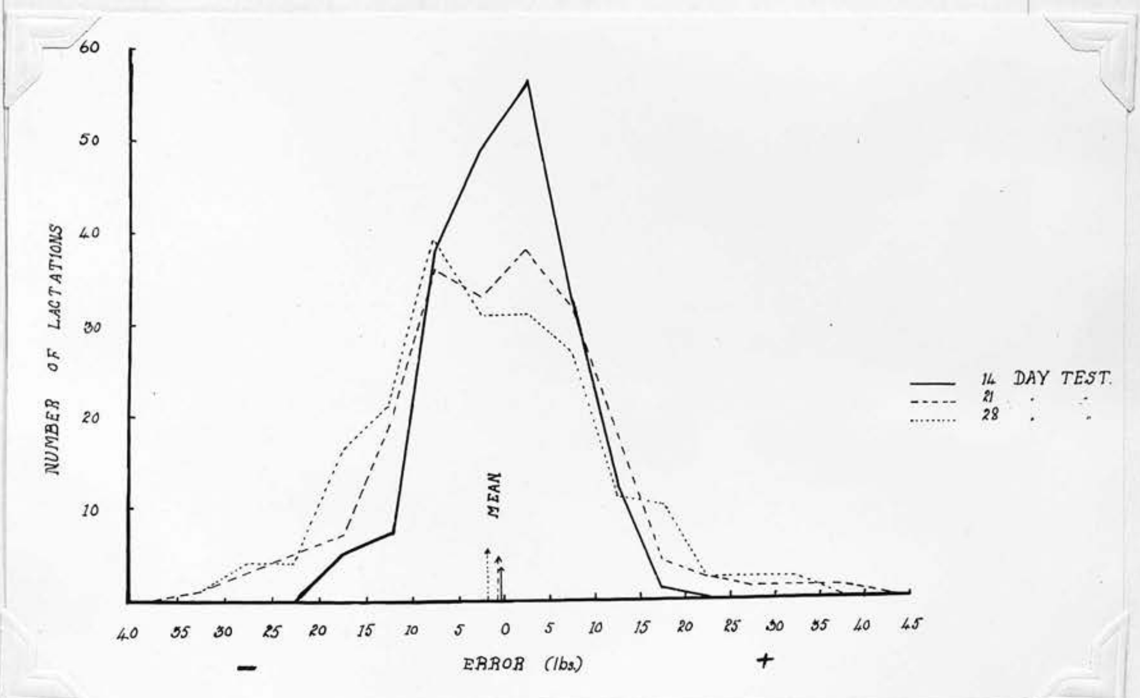


TABLE 21.

The Distribution of Percentage Error in Fat Yield calculated by the Different Methods.

Percentage deviation		14-day	21-day	28-day
+	10 - 12	0	1	0
+	8 - 10	0	1	3
+	6 - 8	0	3	4
+	4 - 6	3	6	12
+	2 - 4	20	33	21
+	0 - 2	79	53	45
-	0 - 2	69	56	48
-	2 - 4	27	27	41
-	4 - 6	2	15	21
-	6 - 8	1	4	5
-	8 - 10	0	1	1
-	10 - 12	0	1	0
TOTAL		201	201	201

Statistical Analysis of the Data.

The results of the statistical analysis of the data are given in Table 22. It is seen that in general the calculated yield obtained with any one of the three methods lies below the 7-day test figures and the mean difference becomes greater as the test interval is prolonged. The value of σ for the difference indicates that the degree of variability of the negative deviation of the calculated yield increases with the increased duration of the test interval, and that such an increase is more pronounced when the interval is changed from 14 to 21 days than from 21 to 28 days.

The range of variation of the recorded yield ($M \pm 2\sigma$) was calculated for each method and is given in Table 23. The figures show that the expected deviation rises with the increase of the test interval but more rapidly for fat than for milk yield. The difference between the 21- and 28-day tests as regards the range of variation, is insignificant, or at least very much smaller than that between the 14- and 21-day tests. These findings agree with the results obtained by most of the writers who investigated the relative accuracy of testing at intervals of 21 and 28 days, e.g. VOGEL, (1931), and RINGLER (1937).

If 354.144 lbs., the mean yield of the 201 records studied, is taken as 100, the relative values for ,

limits/

TABLE 22.

Statistical Analysis of Data for Fat Yield recorded by the Different Methods.

		14-day Test	21-day Test	28-day Test
Mean lactation yield (weekly tests)	lbs.	354.144 $\pm$ 5.796	354.144 $\pm$ 5.796	354.144 $\pm$ 5.796
Mean error (recorded - weekly)	lbs.	-.527 $\pm$ .447	-.667 $\pm$ .738	-1.930 $\pm$ .786
Standard deviation of the weekly test figures	lbs.	82.17 $\pm$ 4.098	82.17 $\pm$ 4.098	82.17 $\pm$ 4.098
Standard deviation of the differences.	lbs.	6.34 $\pm$ .316	10.49 $\pm$ .522	11.14 $\pm$ .556
Maximum error (increase)	lbs.	16	39	31
Maximum error (decrease)	lbs.	18	30	30
Range of variation	lbs.	34	69	61
Maximum % of error (increase)		4.92	10.10	8.86
Maximum % of error (decrease)		6.01	11.24	9.48
Range of variation in %		10.93	21.34	18.34

TABLE 23.

Absolute Variation of fat yield recorded by the Different Methods.

Test	σ	2σ	Mean lbs.	$M \pm 2\sigma$	Range of Variation.
14-day	6.34	12.68	353.617	340.937 lbs. - 366.297 lbs.	25.360 lbs.
21-day	10.49	20.98	353.477	332.497 lbs. - 374.457 lbs.	41.960 lbs.
28-day	11.14	22.28	352.214	329.934 lbs. - 374.494 lbs.	44.560 lbs.

TABLE 24.

Relative Variation of Fat Yield Recorded by the Different Methods.

Test	σ	2σ	Mean	$M \pm 2\sigma$	Range of Variation.
14-day	1.7902	3.5804	99.8512	96.2708 - 103.4316	7.1608
21-day	2.9621	5.9242	99.8117	93.8875 - 105.7359	11.8484
28-day	3.1456	6.2912	99.4550	93.1638 - 105.7462	12.5824

limits and ranges of variation are obtained. The results are given in Table 24 and shown graphically in Fig.4.

The accuracy of the recorded fat yield as affected by the size of the yield.

In view of the disagreement between the various writers concerning this point and for the reasons mentioned in the case of milk yield, special attention was paid to the extent to which the accuracy of the calculated yield might be influenced by the total fat yield within the lactation.

The correlation coefficient between the 7-day test figures and the difference was calculated separately for each of the three methods, and in order to express the relation in quantitative terms, the regression coefficient for the same variates was also established. Table 25 gives the results obtained.

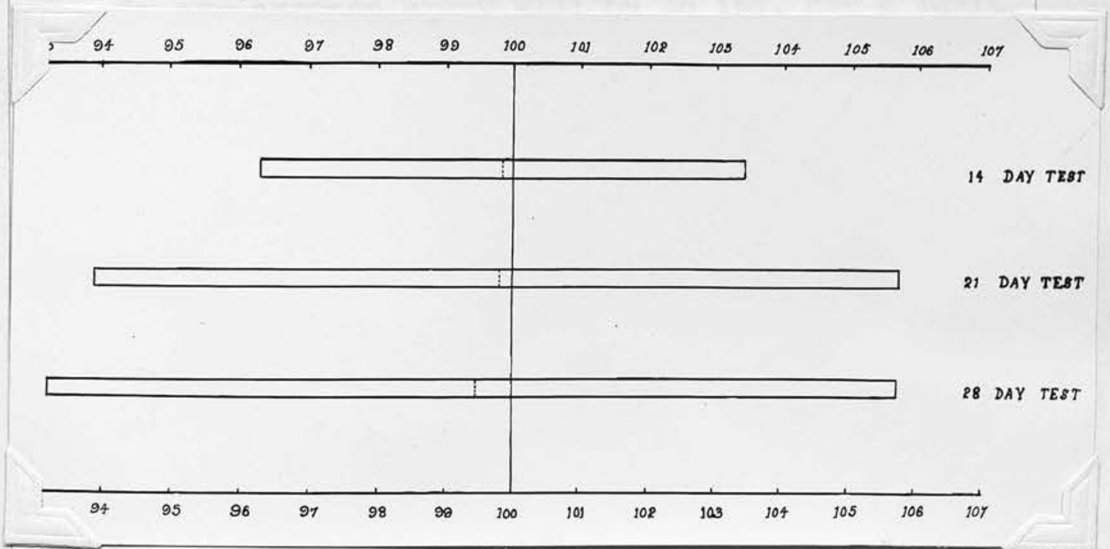
TABLE 25.

Correlation between Fat Yield and Error.

	14-day	21-day	28-day
Correlation coefficient	-.194 ± .068	-.008 ± .071	-.074 ± .070
Regression coefficient	-.015	-.001	-.010

The/

Fig.4. Graphic representation of M $\pm$ 2σ, i.e. the range of variation in fat yield calculated by the different methods.



The negative correlation established in each of the three systems shows that the error decreases with the increase of the yield, but in view of the fact that in none of these cases does the correlation exceed three times its standard error, the variation in the difference is considered insignificant. The regression coefficient indicates that in extreme cases the variation in the average error will be 15 lbs. for a variation in the yield of 1000 lbs.

It seems justifiable to conclude that the correlation between the yield and the error is insignificant and that the accuracy of the records depends largely on the method of calculating the yield, the length of the test interval, the duration of the test period, and other factors discussed at the beginning of the paper, and not on the total yield.

SECTION II.

THE ACCURACY OF THE SYSTEM OF RECORDING ADOPTED BY THE SCOTTISH MILK RECORDING SOCIETIES.

Hitherto all studies on the accuracy of milk recording have, so far as the author is aware, been based on theory and not on actual measurements. Various errors that may arise have been considered as they would work out in theory, but not as they worked in practice. Thus, these observations were based on actual lactation records, but not on the lactation records as calculated by the system in vogue. Accordingly, the main part of this study deals with an examination of the official records of the Scottish Milk Recording Society at the farms of Shothead and Cockburn as compared to the actual records taken by the staff of the Institute of Animal Genetics.

Development of Milk-Recording.

In Scotland there are at present two Schemes of milk recording in operation, both under the direction of the Scottish Milk Records Association: a scheme of official, authenticated milk records and a scheme of private or unofficial milk records. The present study is concerned with the official scheme which was inaugurated in 1903, when the National Agricultural Society set aside a sum for the promotion and encouragement/

encouragement of systematic milk recording and this grant was renewed in the following years. In 1908 milk recording was transferred to the Ayrshire Cattle Milk Records Committee. In 1909 a grant was received from the Ayrshire Cattle Herdbook Society, in addition to that from the National Agricultural Society. In 1910 the name was changed to "The Scottish Milk Records Committee". A new grant to the Scottish Milk Records Committee was made in 1912 by the West of Scotland Agricultural College. In 1914 the Scottish Milk Records Association was formally created with a scheme approved by the Department of Agriculture for Scotland and the Development Commissioners, and an annual grant was obtained and more complete arrangements made for the direction and supervision of recording and the revision of the records by officials of the Association.

Method of Milk Recording.

Under this scheme the official recorder visits each herd at regular intervals of not more than 28 days, usually 20-25 days. Each visit lasts 24 hours from one evening to the evening of the following day. The cows are milked in the same rotation, evening and morning, on the occasion of the recorder's visit.

The recorder weighs and samples the milk of each cow at the evening and the morning milkings and enters the results in the byre sheet. The samples of the evening milk are securely locked up overnight and during/

during the absence of the recorder. After the morning milking the mixed evening and morning sample for each cow is tested for percentage of milk fat by the Gerber method. The recorder enters in the byre sheet any unusual conditions likely to affect the yield. He transfers the results from the byre sheets to the milk record book.

Two or three times throughout the year the records of each herd are checked by a surprise check test. For this purpose the recorder is instructed on a date unknown to recorder and owner of herd to remain at the same farm another day and make another complete 24 hours' test. In addition to the surprise tests made by the recorder, a number of independent surprise tests are made by the Association's staff, in order to check the recorder's work.

For calculating milk and fat yields the official instructions are as follows: For the first test of lactation, multiply the total yield on the test day by the number of days which have elapsed since the cow calved, plus half the number of days in the average interval between the tests. On the second and each succeeding test, multiply the yield by the actual number of days which have elapsed between tests, thus regarding each day of test as the middle of the test interval. At the end of the lactation figures representing the yield during the test intervals are added up to give the total performance. This is done both for milk and fat yields from which the average fat percentage is calculated.

TREATMENT OF MATERIAL.

The material collected for this study consists of records of two Ayrshire herds at the experimental farms, Cockburn and Shothead, covering the period from 1931 to 1937. The figures derived from these records were compared with those taken from the official books of the Scottish Milk Recording Society for the same cows and for the corresponding lactation periods.

In collecting these data only complete lactations were considered and no lactations were included if

(a) there was any illness,
(b) there was a period during which entries were missing, either in the farms' records or in the Scottish Milk Recording Society's books,
(c) a period of the lactation was estimated,
(d) there were any abnormal conditions.

267 completely normal lactations for milk yield and 248 for fat yield were available. At the outset, it was obvious that a major discrepency existed between the two sets of records in view of the fact that the lengths of the lactation periods shewed some variation. It was seldom that the official lactation period was the same as the actual period. To eliminate this, the lactation yields were recalculated so that, for both farms and official records, the period was exactly the same.

RESULTS/

RESULTS AND DISCUSSION.

MILK YIELD.

The 267 lactations studied were classified into groups according to the yield. This was done both for the actual figures and those given by the Scottish Milk Recording Society. The mean yields for complete lactations were 8940.34 lbs.and 9390.61 lbs. respectively. The frequency distributions for these two systems are given in Table 26 and illustrated in the form of a frequency polygon in Fig.5. It will be seen that in both cases the distribution is normal and the curve representing the S.M.R.S. records is bodily moved towards the high figures, indicating that in general there is a tendency for the calculated yield under the Scottish scheme to exceed the actual performance. This is not in agreement with the conclusions of MacCANDLISH and M'VICAR, (1925), who reported that in calculating milk yield according to the Scottish Milk Record Association's method, about the same number of individual records show an increase as show a decrease, and consequently the chances are about even that a calculated record may be either slightly greater or slightly less than the actual. Further evidence to support our finding was derived from a study of the individual records. It was found that in 252 cases out of 267 the S.M.R.S. estimations were higher than the actual yield, while the reverse was true for only 15 records.

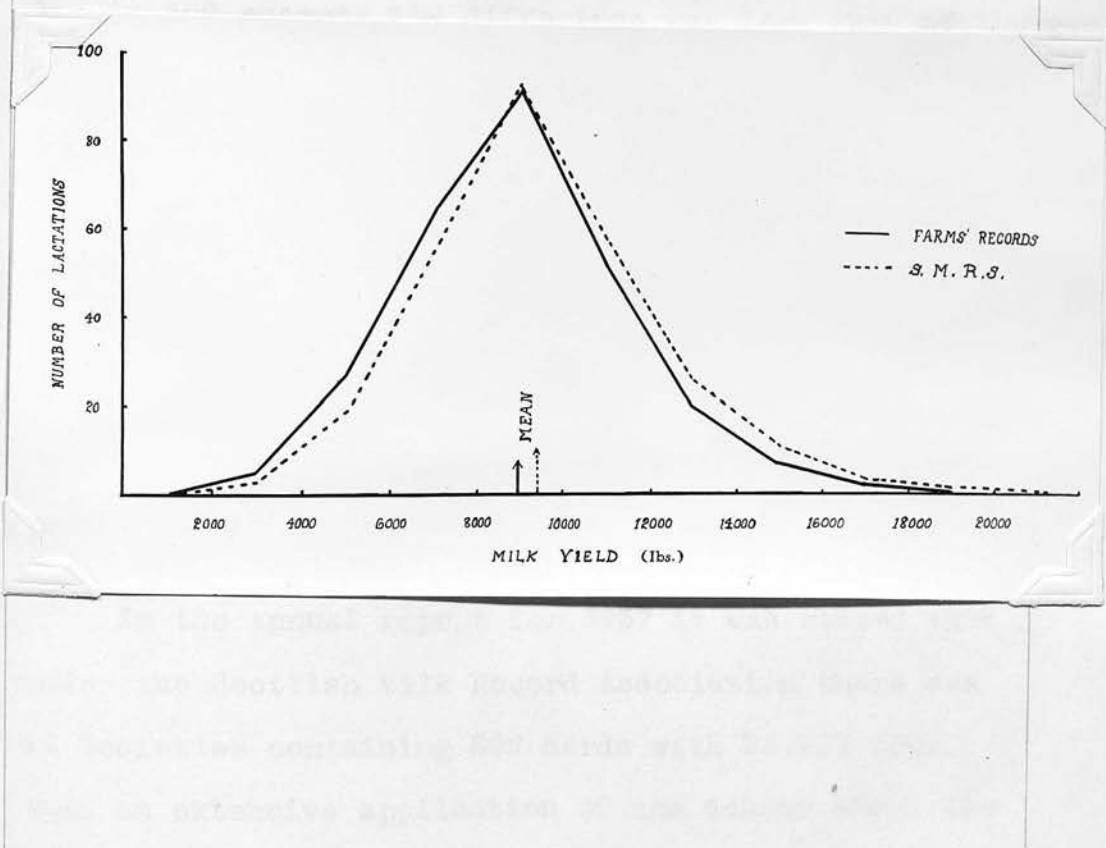
The/

TABLE 26.

The Distribution of the Lactation Milk Yield for the Farms' and the Scottish Records.

Lactation yield in lbs.	Number of Lactations	
	Actual	S.M.R.S.
2000 - 4000	5	3
4000 - 6000	27	19
6000 - 8000	64	55
8000 - 10000	91	92
10000 - 12000	51	57
12000 - 14000	20	26
14000 - 16000	7	11
16000 - 18000	2	3
18000 - 20000	0	1
TOTAL	267	267

Fig.5. Distribution of Milk Yield for the farms' and S.M.R.S. records.



The difference between the calculated and the actual yield was determined separately for each lactation and the distribution obtained is given in Table 27. The mean difference was 450.27 lbs. above the actual. When the deviation was expressed as a percentage of the farms' figures it was found that:-

1. in 109 records the difference was less than 5% above the actual.
2. in 124 records the difference fell between 5 and 10% above the actual.
3. in 18 records the difference fell between 10 and 15% above the actual.
4. one record showed a difference of more than 30% above the actual.
5. all the 15 cases which gave negative deviation showed a difference of less than 5%.

Statistical Analysis of the Data.

In the annual report for 1937 it was stated that under the Scottish Milk Record Association there are 41 Societies containing 800 herds with 36,221 cows. Such an extensive application of the scheme shows the necessity for analysing the data statistically in order to determine the degree of the probability of the results obtained in the present investigation if a similar study is carried out in another herd recorded by the same method and under similar prevailing conditions.

While discussing the results reference will also be made to the work of M'CANDLISH and M'VICAR (1925), as/

TABLE 27.

The Distribution of the Absolute Error in Milk Yield recorded under the Scottish System.

Deviation in lbs.		Number of Lactations.
+	2400 - 2700	0
+	2100 - 2400	1
+	1800 - 2100	1
+	1500 - 1800	0
+	1200 - 1500	2
+	900 - 1200	11
+	600 - 900	59
+	300 - 600	118
+	0 - 300	60
-	0 - 300	12
-	300 - 600	3
-	600 - 900	0
TOTAL		267

as their study is the only one in literature dealing directly with the scheme in question. It should be noted, however, that their conclusions were drawn from data which entailed only 24 lactations. Moreover, the figures compared with the actual production were not derived from the S.M.R.S. books but were calculated from daily recordings of the authors. Though M'CANDLISH and M'VICAR applied carefully the instructions given by the Association their figures are probably not identical with those which would have been given by the official recorder.

The true average of the records studied is 8940.34 $\pm$ 155.97 lbs. and the yields obtained from the S.R.M.S. books show an average of 9390.61 $\pm$ 161.09 lbs., or an increase of 450.27 $\pm$ 19.64 lbs.

In order to determine the range of variation round the mean the standard deviation was calculated for the actual records, the S.M.R.S. figures and the errors. The values obtained were 2548.51 $\pm$ 110.28, 2632.21 $\pm$ 113.91 and 320.94 $\pm$ 13.89 respectively. It is noted that the standard deviations for the actual and the calculated figures are close to each other, which indicates that in both cases the individual yields are scattered about the mean to the same extent and therefore the inaccuracy involved in the S.M.R.S. method is largely systematic.

On the assumption that 95% of the variates differ from the mean by no more than twice the value of the standard/

standard deviation, it may be assumed that the range of variation for the S.M.R.S. estimations will be from 8748.73 lbs. to 10032.49 lbs.

To facilitate comparison between the results obtained and those given by other systems, relative values in which the average true yield 8940.34 lbs. is taken as 100 have been calculated and are given in Table 28.

TABLE 28.

Relative Values of Means and Standard Deviations of Milk Yield Recorded under the Scottish System.

Mean actual yield.	100
Mean recorded yield.	105.0364
Mean error.	5.0364
Standard deviation of the actual yield.	28.5058
Standard deviation of the calculated yield	29.4419
Standard deviation of the error.	3.5898
Limits of variation ($M \pm 2\sigma$)	97.8568 - 112.2160
Range of variation	14.3592

The corresponding figures given by M'CANDLISH and M'VICAR (cf. p. 27) are comparatively low. They established a mean error of 50 lbs. and 10 lbs. increase/

increase when tests were taken at 20- and 30-day intervals respectively. As the mean actual yield for the experimental animals was 6420 lbs. such errors are of no significance since the deviation from the true average is less than 1 per cent.

It is important to notice not only the average results from the records studied but also the maximum errors that occur in the individual cases, though it should be borne in mind that the maximum errors found in any particular investigation does not indicate the greatest possible errors involved in the methods of recording studied.

The limits of variation of the individual records were from a decrease of 517 lbs. to an increase of 2146 lbs. i.e. a range of 2663 lbs. It is hardly necessary to point out that such a high maximum error and wide range of variation will depreciate the practical value of the results.

A better idea of the reliability of the system may be obtained by expressing the maximum errors and the range of variation as percentages of the actual production. These values are:-

Maximum error (increase)	31.63%
Maximum error (decrease)	4.83%
Range of variation	36.46%

In this respect M'CANDLISH and M'VICAR found that the/

the variations of the calculated records are from a decrease of 130 lbs. to an increase of 240 lbs., or a range of 370 lbs., in the case of 20-day interval; and from a decrease of 360 lbs. to an increase of 460 lbs., i.e. a range of 820 lbs., in the case of the 30-day interval.

Relation between Yield and Error.

Few writers attempted to determine the influence of the total milk yield upon the accuracy of the record and since there exists no concensus of opinion and, moreover, the question was not considered in connection with the system of recording studied, it is desirable to investigate the point now in order to throw some light on the matter.

From a study of the individual records it was observed that the error obtained was greater with high yielders than in the case of low yielders. This observation was confirmed by calculating the correlation coefficient between the actual yield and the error. This was found to be + .2827 $\pm$ .0563. The value of the correlation is low but it is significant.

Since the correlation shows that with the increase of the yield there is a corresponding increase in the error, the next step was to measure that increase quantitatively. For this purpose the regression coefficient of the error on the actual production was calculated/

calculated and was found to be +.0356, a value which indicates that a variation of 1000 lbs. in the actual milk yield will be followed by a variation of 35.6 lbs. in the error.

By using the regression equation $E = \bar{y} + b\ (X - \bar{x})$ where

E = the error

$\bar{y}$ = the mean error (+ 450.27 lbs.)

b = the regression (+.0356)

X = the actual yield

$\bar{x}$ = the mean actual yield (8940.34 lbs.)

it is possible to ascertain the error which would be expected for any given yield. Fig.6 gives the regression line obtained, with a dot diagram for the actual yields and the corresponding errors. It will be seen that the points are equally distributed on both sides of the line.

In Table 29 the results are summarised.

Fig.6. Regression of the error on the lactation milk yield.

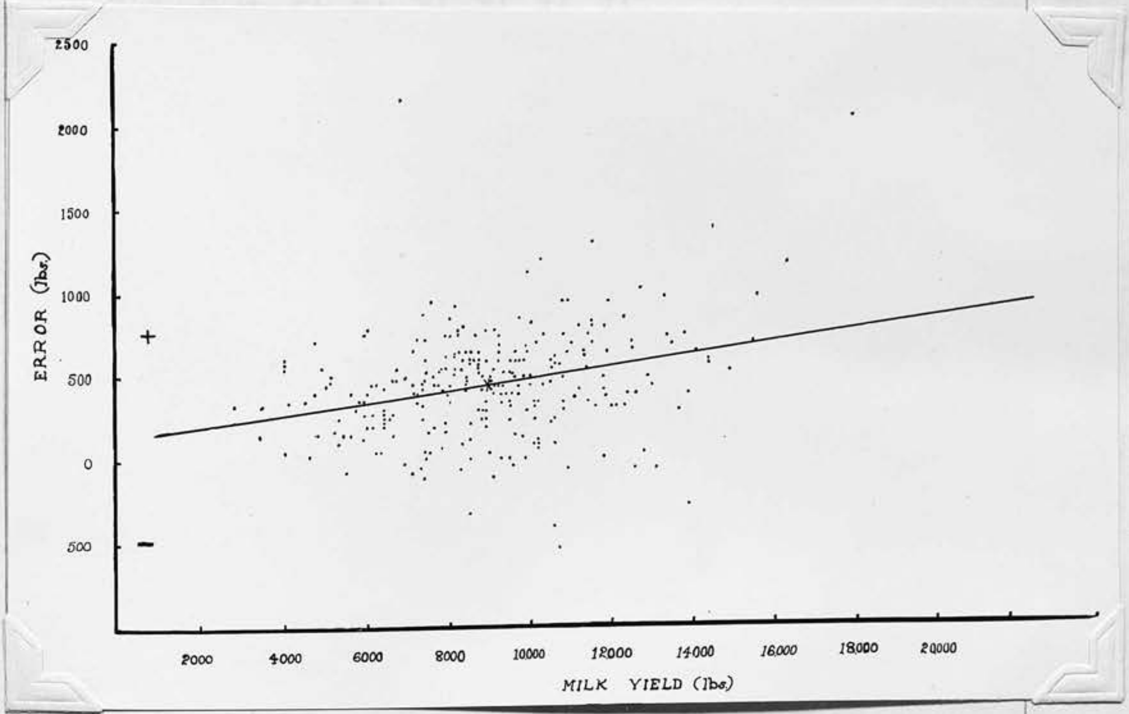


TABLE 29.

Statistical Analysis of Data for Milk Yield Recorded under the Scottish System.

		Value ± standard error
Mean actual yield	lbs.	8940.34 ± 155.97
Mean recorded yield (S.M.R.S.)	lbs.	9390.61 ± 161.09
Mean error	lbs.	+450.27 ± 19.64
Standard deviation of the actual yield	lbs.	2548.51 ± 110.28
Standard deviation of the recorded yield	lbs.	2632.21 ± 113.91
Standard deviation of the error	lbs.	320.94 ± 13.89
Maximum error (increase)	lbs.	2146
Maximum error (decrease)	lbs.	517
Range of variation		2663
Maximum percentage of error (increase)		31.63
Maximum percentage of error (decrease)		4.83
Range of variation in percentage		36.46
Correlation coefficient between the actual yield and the error		+.2827 ± .0563
Regression coefficient of theerror on the actual yield		+.0356

FAT YIELD.

The study of fat yield was carried out on the same lines as that for milk yield. The farms' figures which are calculated from weekly tests for fat percentage and the actual milk yield were taken as the basis as they give the nearest approximations to the actual fat yield.

A number of 248 completely normal lactations was available, and both the farms' and the S.M.R.S. records were divided into groups with an interval of 50 lbs. The mean yield for a complete lactation was 332.85 lbs. and 360.54 lbs. respectively. The frequency distributions for these two systems are shown in Table 30 and are further illustrated in Fig.7.

It is evident that the frequencies of the high yielder groups are larger in the case of the S.M.R.S. than in the farms' records while the reverse is the case with the low yielder groups. This indicates that a yield estimated by the S.M.R.S. method is more likely to exceed the value given by the farms than to be less. A study of individual records confirms this point, as it reveals that in 218 out of 248 instances the estimations of the S.M.R.S. exceeded the farms' figures while the opposite tendency was apparent in only 30 cases.

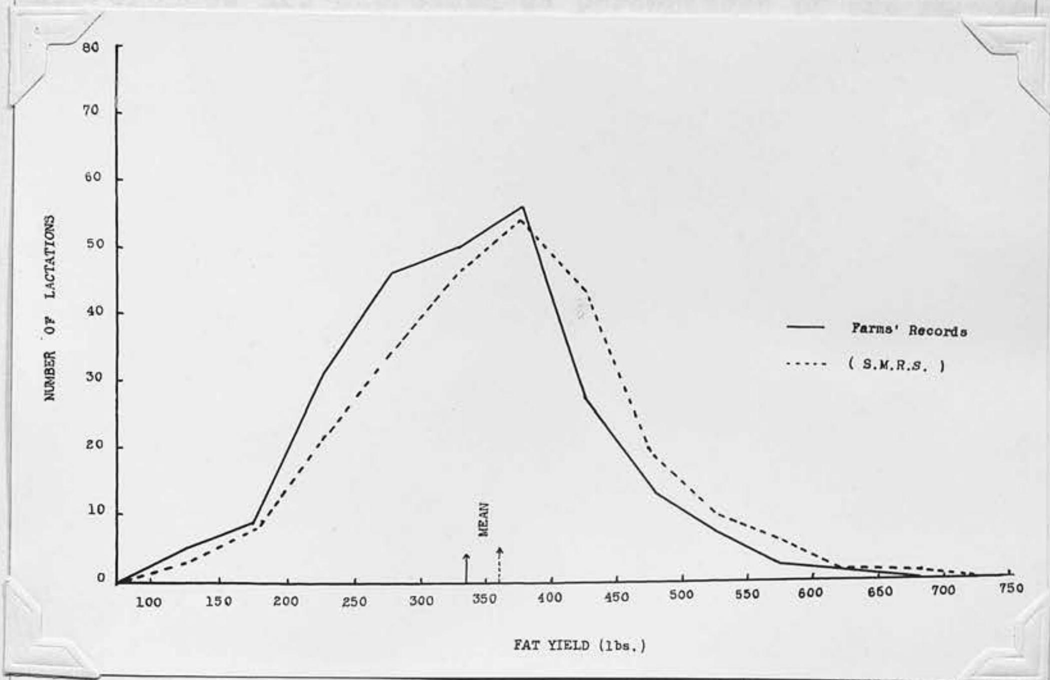
On/

TABLE 30.

The Distribution of the Lactation Fat Yield for the Farms' and the Scottish Records.

Lactation Yield in lbs.	Number of lactations.	
	Farms	S.M.R.S.
100 - 150	5	3
150 - 200	9	8
200 - 250	31	22
250 - 300	46	34
300 - 350	50	46
350 - 400	56	54
400 - 450	27	43
450 - 500	14	19
500 - 550	7	10
550 - 600	2	6
600 - 650	1	1
650 - 700	0	1
700 - 750	0	0
750 - 800	0	1
TOTAL	248	248

Fig.7. Distribution of fat yield for the farms' and S.M.R.S. records.



On comparing the two sets of records the difference was determined separately for each lactation and the results obtained are summarised in Table 31. The mean difference was 27.69 lbs. above the farms' figures.

A better idea of the extent of the errors may be obtained from a study of Table 32, in which the differences are expressed as percentages of the farms' figures and the individuals are classified into groups according to the percentage of error. By comparing these results with the corresponding values for milk it will be noticed that the error is much more pronounced in the case of fat. In the majority of cases, however, the divergence of the fat yield estimated by the S.M.R.S. from the farms' records is considerable.

Statistical Analysis of the Data.

Similarly to the case of milk yield, the data were analysed statistically and the results will be discussed briefly as they show the same trend as those for milk yield.

The mean lactation yield for the farms' records is 332.85 $\pm$ 5.69 lbs. while that given by the S.M.R.S. average 360.54 $\pm$ 6.31 lbs. showing, on the average, an increase of 27.69 $\pm$ 1.69 lbs.

In order to give a good picture of the degree of variability in the different estimates, the standard deviation/

TABLE 31.

The Distribution of the Absolute Error in Fat Yield recorded under the Scottish System.

	Deviation in lbs.	Number of lactations.
+	180 - 210	0
+	150 - 180	1
+	120 - 150	2
+	90 - 120	3
+	60 - 90	14
+	30 - 60	83
+	0 - 30	115
-	0 - 30	26
-	30 - 60	4
-	60 - 90	0
	TOTAL	248

TABLE 32.

The Distribution of Percentage Error in Fat Yield recorded under the Scottish System.

	Percentage Deviation.	Number of Lactations.
+	35 - 40	1
	30 - 35	1
	25 - 30	7
	20 - 25	9
	15 - 20	21
	10 - 15	58
	5 - 10	71
	0 - 5	50
-	0 - 5	23
	5 - 10	6
	10 - 15	1
	15 - 20	0
	TOTAL	248

deviation for the farms' records, the S.M.R.S. figures and the errors was determined. The values obtained are 89.58 ± 4.02, 99.35 ± 4.46 and 26.65 ± 1.20 lbs. of fat respectively. It is observed that the value referring to the error is comparatively high while the other two values are very similar, indicating that the variates are distributed round the mean in the same way.

Considering that a calculated yield by the S.M.R.S. will differ from the mean value by more than twice the standard deviation in one estimate out of twenty, while the other nineteen estimates are likely to differ by less than twice the standard deviation, it may be assumed that the S.M.R.S. figures will fall between 307.24 lbs. and 413.84 lbs.

Taking the mean fat yield for the farms' records as 100, the relative values of the means and the standard deviations were calculated and are given in Table 33.

TABLE 33.

Relative Value of Means and Standard Deviations of Fat Yield recorded under the Scottish System.

Mean yield (Farms' records)	100
Mean yield (S.M.R.S. records)	108.3191
Mean error	8.3191
Standard deviation of the farms' records	26.9130
Standard deviation of the S.M.R.S. records	29.8483
Standard deviation of the error	8.0066
Limits of variation($M \pm 2\sigma$)	92.3059 - 124.3323
Range of variation	32.0264

As might have been expected, the percentage mean error is much higher in the case of fat yield than milk yield. Moreover the range of variation for the former is more than twice that for the latter, namely 32 as compared with 14. This can be attributed to double error, both working in the same direction, firstly, error in the estimation of fat by itself, and secondly, error arising from the calculation of the total yield of fat from a figure (yield of milk) already subject to error.

Next in importance to the mean error and the degree of its variability is a knowledge of the maximum errors which may occur. The limits of variation were found to be from a decrease of 49 lbs. to an increase of 169 lbs, or a range of 218 lbs. When the error was expressed as a percentage of the farms' figures the following values were obtained:-

Maximum error (increase)	36.72%
Maximum error (decrease)	11.25%
Range of variation	47.97

The relation between fat yield and error.

The correlation coefficient between the farms' figures and the errors was calculated and gave a value of $+.1943 \pm .0611$. This is not a high correlation, but it indicates that the error introduced by the S.M.R.S. rises as the fat yield increases.

For/

For the same reason as in the case of milk the regression coefficient of the error on the yield was determined and its value was found to be + .0578. It shows that each 100 lbs. variation in the fat yield is accompanied by 5.78 lbs. difference in the error. By using the regression equation already described, it is possible to estimate the error to be expected with any given yield. Fig.8 gives the regression line obtained, with a dot diagram for fat yield as taken from the farms' records and the corresponding error.

The actual analysis.

Under the official system, the method of calculation of the butterfat percentage for each daily test is different from that employed for the farm records. In the official system aliquot samples of each milking are mixed, analysed, and the percentage calculated for the mixed sample. For the farms' records, the percentage is calculated for each milking, then for the total daily production. Comparisons of the figures of the official recorder with those recorded by the farm staff for the same day shows a certain discrepancy, which was distinctly greater with certain recorders than others. On occasion, it was obvious that the official recorder had got the samples mixed. Here quite certainly lies one source of error in the estimation of the official fat yield. Careless sampling probably does not contribute/

contribute to the error since the error in this respect was no larger for Shothead than for Cockburn, where an auto-recorder milking machine is employed which ensures adequate mixing of the milk before sampling, and which has been shown to be reliable by special tests. Another source of error arises from the fact that at Cockburn and Shothead milkings are at equal intervals whereas this seldom occurs in practice. Thus in practice error may arise from the incorrect measurement of the alignot samples used for the composite sample for analysis of the butterfat.

Table 34 gives a summary of the results.

TABLE 34.

Fig.8. Regression of the error on the lactation fat yield.

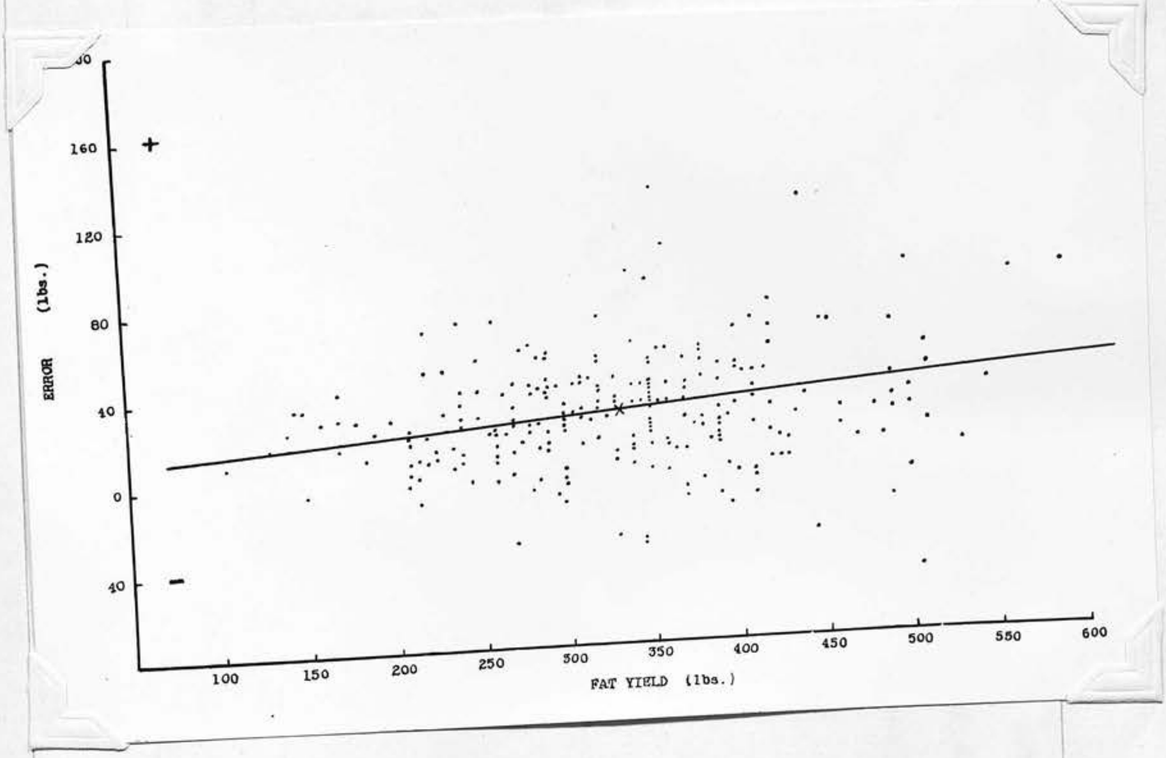


TABLE 34.

Statistical Analysis of Data for Fat Yield recorded under the Scottish System.

		Value ± standard error
Mean yield (farms)	lbs.	332.85 ± 5.69
Mean yield (S.R.M.S.)	lbs.	360.54 ± 6.31
Mean error	lbs.	+27.69 ± 1.69
Standard deviation of the farms' figures	lbs.	89.58 ± 4.02
Standard deviation of the S.M.R.S. figures	lbs.	99.35 ± 4.46
Standard deviation of the error	lbs.	26.65 ± 1.20
Maximum error (increase)	lbs.	169
Maximum error (decrease)	lbs.	49
Range of variation	lbs.	218
Maximum percentage of error (increase)		36.72
Maximum percentage of error (decrease)		11.25
Range of variation in percentage		47.97
Correlation coefficient between the farm figures and the error		+.1943 ± .0611
Regression coefficient of the error on the farms figures		+.0578

FAT PERCENTAGE.

In the two systems of recording - farms and S.M.R.S.- the average fat percentage for the lactation is calculated from the formula:-

$$\text{Fat percentage} = \frac{\text{fat yield in lbs.}}{\text{milk yield in lbs.}} \times 100$$

Therefore the accuracy of the value obtained varies with the degree of reliability of the method used in estimating milk and fat yields, a question which has been previously discussed in connection with each system.

Tables were also compiled in which the two sets of fat percentages were compared and the difference was determined separately for each lactation. As would be expected, a great range of variation occurred and the mean difference was .13% above the farms' figures. In an extreme case the deviation amounted to .75%.

LACTATION PERIOD.

As already stated in these comparisons between the farms' and official records, all lactations compared were reduced to the same length. In actual practice, however, it was found that in only 33 out of 267 lactations was the value correct. In 153 lactations the official exceeded the actual, and in 81 lactations it/

it was less. 50% of the lactations shewed an excess of at least two weeks of the official over the actual.

In view of the fact that the data are derived from experimental herds where there is not the same incentive to dry off cows immediately after the final visit of the recorder, as is so frequently the case in certain pedigree herds, it is probable that this difference is even greater under ordinary farm conditions. Thus the error of the official record over actual yield may be increased by another 100 lbs. in the case of milk yield and 4 lbs. in butterfat.

THE ACTUAL RECORDER.

During the period under review three different recorders were employed by the Scottish Milk Association on the circuit. It was soon apparent that some of these performed their work more conscientiously than others. Accordingly, as regards milk and fat yield, the errors of the lactations made under the supervision of each recorder were tabulated separately and the mean error of each calculated. The figures obtained were

Milk Yield.

	No. of Lactations	Mean Yield lbs.	Mean Error lbs.	S.D. of Error
Recorder No.1	114	8502	+ 466	268.9
" " 2	143	8059	+ 408	403.9
" " 3	45	9254	+ 328	372.0

Fat Yield.

	No. of Lactations	Mean Yield lbs.	Mean Error lbs.	S.D. of Error
Recorder No.1.	89	322	+ 22	19.13
" " 2	143	304	+ 29	31.45
" " 3	45	345	+ 19	25.55

HIGH YIELDERS.

Returning to the point of high-yielding cows, it has been shown that there is a small positive correlation between the yield both of milk and butterfat with the percentage error of the official records. A 5% error with a yield of 8000 lbs. is not very serious as it amounts to only 400 lbs., but with a 15000 lbs. lactation yield, a 6% error becomes 900 lbs.
With fat yield the error is greater, 8% at 200 lbs. fat is only 16 lbs., but 9% at 500 lbs. is 45 lbs.
Thus the gross error of high yielders may be considerable, and its importance will be appreciated when it is remembered that it is cows of the highest grade which are used for selection and genetical improvement.
The maximum error of + 37% obtained when applied to a cow giving 500 lbs. increases her yield by 185 lbs. to nearly 700 lbs. True, the error amounts to 25% in only 3.5% of all the lactations, but when such an error occurs/

occurs in a high yielder, it becomes one of the first magnitude since it is on such animals that the selection of breeding stocks, and more particularly of bulls, is based.

SECTION III.

THE RELIABILITY OF THE SYSTEM OF RECORDING USED IN ENGLAND AND WALES.

Development and Organisation of Milk Recording.

The first Milk Recording Society in England and Wales was formed in April, 1914, and since then the movement has made considerable progress. From 1927 to 1933 there was a decrease in membership due to continued depression in agriculture which has caused a certain number of herd owners to resign their membership of Milk Recording Societies in order to reduce their outdoings. From 1934 the movement started to gather fresh energy, and since then the number of cows tested has been increasing.

The Ministry of Agriculture and Fisheries has established a Scheme under which grants are made to Milk Recording Societies which adopt and adhere to rules conforming substantially to the model rules issued by the Ministry. A Milk Recording Society generally operates in one or more entire counties and must consist of not less than ten members owning between them at least 100 cows.

The testing of milk for fat has been carried out by Milk Recording Societies unofficially in the past, but/

but on 1 October 1933, the Ministry introduced a uniform scheme for sampling and testing for fat.

The Ministry's Regulations Relating to Recording Milk and Testing for Fat.

According to the rules laid down by the Ministry, each member of a Milk Recording Society must weigh the milk of each cow in the herd at every milking during the day, either daily or on one day in each week. For the purposes of the Scheme, a day commences at midday.

The recorders are required on at least eight occasions during the year, and at intervals of about 6 weeks but not more than 8 weeks, to visit each herd at milking time in the evening and in the morning, or at each milking if a cow is milked more than twice daily. Samples from each milking are taken and tested separately for fat and the results of the tests are entered separately in the Annual Register.

In the case of a member who takes weekly weighings of the milk yield of his cows and has samples taken for testing for fat, the day of the recorder's visit shall be other than the ordinary weekly weighing day.

Samples shall not be taken within 10 days after the cow has calved or aborted: nor, in cases where the cow has suckled a calf, until 3 days after suckling has ceased:/

ceased; nor when the cow is milked only once daily; nor when the cow's total yield of milk for the day is less than 8 lbs.

At every visit the recorder shall examine the yields of milk recorded at each milking for several days immediately preceding that on which the samples are taken in the case of daily weighings, and for several weeks preceding in the case of weekly weighings. Should the yield of milk of any cow from which a sample is taken be found materially different from that of preceding and corresponding milkings for that cow, a note giving the yields at each milking for two preceding weighing days, and any explanation that may be available of the variation in yield, shall be forwarded with the sample to the testing authority.

It shall be within the power of the Milk Recording Society to take additional samples as it may deem desirable, and within the right of the members to ask for such additional samples to be taken. If such additional samples are taken because a sample taken at the usual time was found to contain an abnormal percentage of fat (high or low), they shall be taken at a surprise visit of the recorder within three weeks of the date of the previous visit, and the results of such samples shall replace the abnormal results for the purpose of calculating the average fat percentage for/

for a milk recording year or other period, and the abnormal results shall be deleted from the Annual Register.

The average percentage of fat for a cow for a milk recording year or other period shall be calculated from the results of the tests taken during such period, as follows:-

From the weight of milk sampled and the percentage of fat found therein by each test, the actual weight of fat yielded on each occasion of sampling shall be ascertained in lbs. to the nearest second place of decimals. At the end of the milk recording year or other period in respect of which an average is required, the average percentage of fat shall be ascertained by calculating the total weight of fat as a percentage of the total weight of milk sampled in the milk recording year or other period. An average percentage of fat in respect of any cow for a milk recording year or other period shall not be recognised by a Milk Recording Society unless it is based on samples taken at each milking on at least five visits of the recorder. The total fat yield of a cow for a milk recording year or a lactation period shall be calculated in lbs. from the milk yield and the average fat percentage during such period.

The milk recording year commences on the evening of/

of the 1st October and ends on the morning of the 1st October the following year. Therefore where a cow calves after October 1st and is dry again before October 1st next year, the lactation period record and the milk recording year record will be the same.

It is to be noted that no farmer is interested in the percentage of fat for the milk recording year as much as that for the lactation period, but the Ministry insists on having the former figure worked out, and apparently it is used for calculating the average fat percentage for the different breeds.

TREATMENT OF MATERIAL.

In our attempt to assess the accuracy of the records calculated under the English Milk Recording Scheme, a number of 211 completely normal lactations were selected from the records of the Experimental Farms, Cockburn and Shothead. For the sake of uniformity and in order to eliminate any breed differences, the investigation was restricted to one breed, viz. pure Ayrshire. As it has been mentioned previously, very accurate individual records are kept for each cow, on these farms, and because of the method in which they are compiled, it was possible to obtain all particulars necessary to calculate yields according to the English system.

By/

By applying carefully the regulations of the Ministry relating to sampling and fat estimation, the average fat percentage for the lactation period was ascertained separately for each case. The fat yield in lbs. for the lactation was calculated from the average fat percentage and the milk yield. The figures obtained are similar to those which would have been given if the same cows were recorded under the English Scheme, provided a certain allowance is made for the sampling error.

RESULTS AND DISCUSSION.

MILK YIELD.

As regards the study of the accuracy of yield of milk by the English system, no further examination was necessary since it was not possible to check the accuracy of farmers' records. The accuracy of weekly tests has already been discussed and was found to be of the order of a mean error of 32 lbs. with a standard error of 75 lbs. in a mean yield 9345 lbs., or roughly a mean error of one third of one per cent. with maximum percentage errors of only 2.52 and 2.45, increase and decrease respectively.

FAT YIELD.

Therefore, it is the fat estimations of the English System that require examination of their accuracy. In order to do this, for each lactation the fat yield calculated according to the English System was compared with the farms' estimates. The average yields were 354.07 lbs. and 349.06 lbs, respectively. A frequency distribution of each of the two sets of records is given in Table 35. In order to show to what extend these distributions diverge or coincide, they were represented graphically in Fig.9. It will be observed that the distributions are not materially different and consequently the two graphs are almost coincident.

A study of the individual records indicates a tendency for the yield calculated by the English method to exceed the farms' figure. It was found that in 141 lactations out of the 211 the value was over-estimated, while in 70 cases it fell below the farms' records.

The deviation of the calculated yield from the farms' estimate was ascertained for each lactation separately, and the frequency distribution is shown in Table 36. In addition the difference was expressed as a percentage of the farms' yield and it was found that:-

1. in 163 cases the deviation fell within $\pm$ 5%
2. in 42 cases it varied from 5% to 10% either below or above the farms' figures.
3. only in 6 cases did the deviation exceed $\pm$ 10%.

Statistical/

TABLE 35.

The Distribution of the Lactation Fat Yield for the Farms' Records and those calculated by the English Method.

Lactation yield in lbs.	Number of Lactations.	
	Farms' Records.	E.S. Records.
150 - 200	0	0
200 - 250	23	22
250 - 300	39	41
300 - 350	49	44
350 - 400	50	50
400 - 450	26	29
450 - 500	14	9
500 - 550	7	13
550 - 600	2	1
600 - 650	1	2
650 - 700	0	0
TOTAL	211	211

Fig.9. Distribution of fat yield for the farms' records and those calculated by the English System.

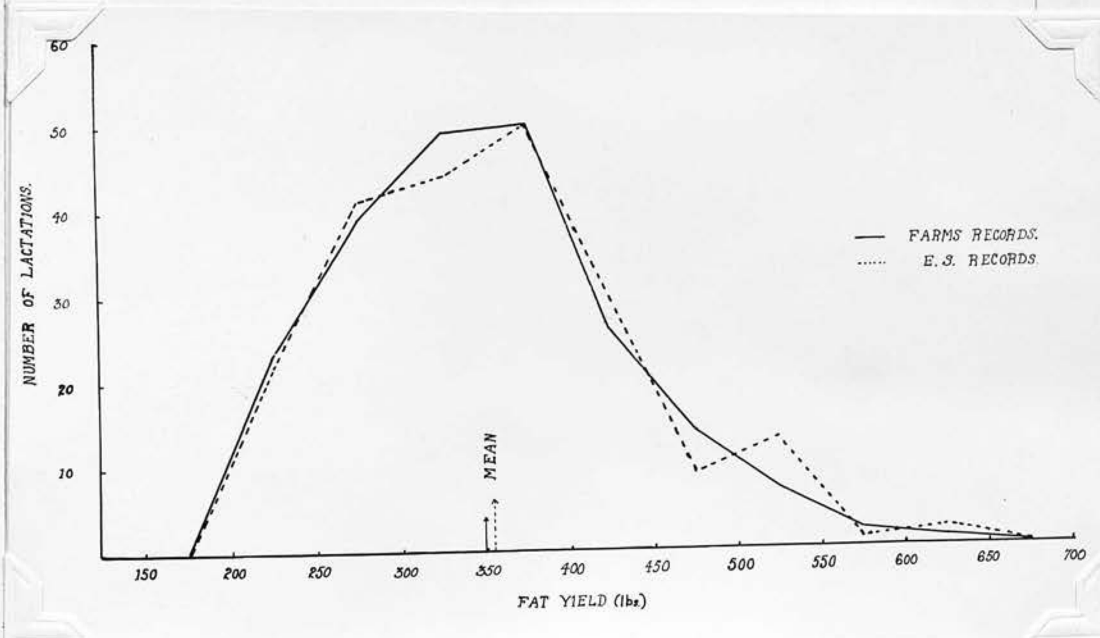


TABLE 36.

The Distribution of the Absolute Error in Fat Yield Calculated by the English Method.

	Deviation in lbs.	Number of Lactations.
+	60 - 80	0
+	40 - 60	2
+	20 - 40	24
+	0 - 20	115
−	0 - 20	65
−	20 - 40	5
−	40 - 60	0
−	60 - 80	0
	TOTAL	211

Statistical Analysis of the Data.

The next step was to analyse the data statistically in the same was as for the other systems. The mean yield of the farms' records is 349.06 $\pm$ 5.56 lbs. and that obtained by the English method of calculation 354.07 $\pm$ 5.78 lbs., or an increase of 5.01 $\pm$ .96 lbs.

In order to show the degree of variability, the standard deviation was determined in each case. It was found to be 80.81 $\pm$ 3.93 for the farms' figures, 84.01 $\pm$ 4.09 for those obtained by applying the English method and 13.90 $\pm$ .68 for the errors.

As any estimate will lie within the range of $M \pm 2\sigma$ on a 95% probability basis, it may be assumed that the values estimated according to the English System will fall between 326.27 lbs. and 381.87 lbs.

To make the results comparable with other systems, relative values were calculated taking 349.06 lbs, the mean lactation yield for the farms' records, as 100. The results are given in Table 37.

TABLE 37.

TABLE 37.

Relative Values for Means and Standard Deviations of Fat Yield Calculated by the English Method.

Mean yield (farms' records)	100
Mean yield (English System)	101.4353
Mean Error	1.4353
Standard deviation of the farms' figures	23.1508
Standard deviation of the English System figures	24.0675
Standard deviation of the error	3.9821
Limits of variation	93.4711 - 109.3995
Range of variation	15.9284

A mean percentage error of 1.44 with a standard deviation of less than 4% shows that the system adopted in England for estimation of the fact is a remarkably good one.

As regards the maximum errors occurring in individual records, an increase of 51 lbs. and a decrease of 37 lbs. or a range of 88 lbs. were established. When the error was expressed as a percentage of the farms' estimates, the following values were obtained:-

Maximum error (increase)	11.91%
Maximum error (decrease)	12.20%
Range of variation	24.11%

Relation between fat yield and error under the English System.

The small error immediately suggests that there can be little or no correlation between fat yield and magnitude of error. This was calculated and found to be +.1138 ± .0627, which is not significant. The regression coefficient of the error on yield is +.0196 which indicates that, for each 100 lbs. variation in the fat yield, there is a difference of 1.96 lbs. in the error. Figure 10 gives the regression diagram for fat yields on the corresponding errors.

Table 38 gives a summary of the results obtained.

Fig.10. Regression of the error on the lactation fat yield.

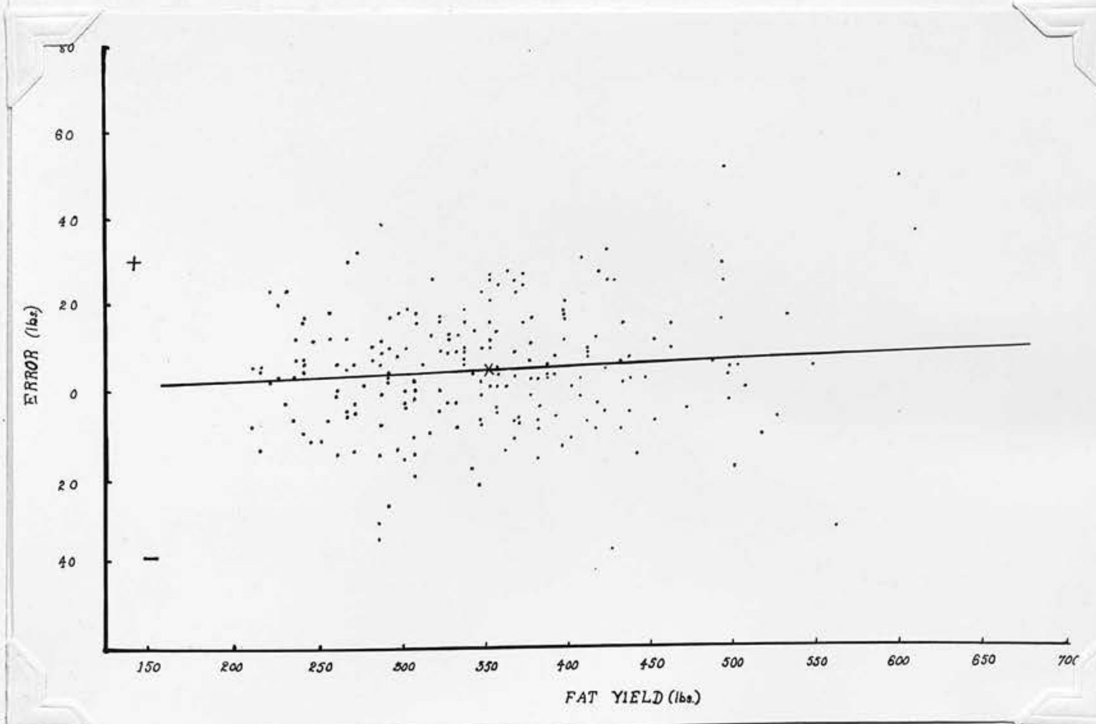


TABLE 38.

Statistical Analysis of Data for Fat Yield Calculated by the English Method.

		Value $\pm$ standard error
Mean yield (Farms' records)	lbs.	349.06 $\pm$ 5.56
Mean yield (E.S. records)	lbs.	354.07 $\pm$ 5.78
Mean error	lbs.	+5.01 $\pm$ .96
Standard deviation of the farms' figures	lbs.	80.81 $\pm$ 3.93
Standard deviation of the E.S. figures	lbs.	84.01 $\pm$ 4.09
Standard deviation of the error	lbs.	13.90 $\pm$ .68
Maximum error (increase)	lbs.	53
Maximum error (decrease)	lbs.	37
Range of variation	lbs.	90
Maximum percentage of error (increase)		11.91
Maximum percentage of error (decrease)		12.20
Range of variation in percentage		24.11
Correlation coefficient between the farms' figures and the error		+.1138 $\pm$ .0627
Regression coefficient of the error on the farms' figures		+.0196

COMPARISON OF THE SCOTTISH AND ENGLISH SYSTEMS.

The system of recording milk in England is so completely different from that employed in Scotland that it has led to much dispute as to which is the better. So far as the writer is aware the two systems have not been critically compared. The major differences of the two systems are tabulated as follows:

	English.	Scottish.
Cows recorded	Those selected by farmer.	All cows in the herd.
Period of record	Yearly to 1st October.	Lactation, stating length in weeks.
Milk	Measured daily or weekly by farmer and checked at intervals of 6-8 weeks by recorder.	Measured at intervals of 3-4 weeks by official recorder. No records kept by farmer.
Fat	Samples taken by recorder at 6-8 weekly intervals and analysed for percentage at laboratory.	Samples taken by recorder at 3-4 weekly intervals and analysed by recorder on farm.
Calculation of fat yield	Percentage for year calculated from results of percentages of all samples taken by recorder.	Calculated in lbs. for each period covered by visit of recorder.

It was not possible to assess the accuracy of the English System in the same way as has been done for the Scottish System since the herds were not under the supervision/

supervision of an English Milk Recording Society, and figures could not be obtained comparable to those from the Scottish Milk Records Association. It was however, possible to examine the method of the English System, but the results obtained from this examination do not bear direct comparison with those obtained for the Scottish System. The following comparison excludes the possibility of error in the English records arising from:-

(a) error in sampling by recorder)) probably very small;
(b) error in analysis of sample)

(c) error in recording milk yield by the farmer;

(d) error in recalculating yearly to lactation yields, probably very small (see paper by LUSH).

In the case of milk yield it is only necessary to take the results of the weekly test as representing the English System for comparison with those of the Scottish System. Relative values in each case were obtained by taking the mean actual lactation yield as 100. The results are given in Table 39. It will be observed that the mean error, its standard deviation and the range of variation are much higher in the case of the Scottish System.

For fat yield Table 40 was compiled in the same manner as Table 39, taking the average lactation yield of the farms' records as 100. A mean error of 1.44% with/

TABLE 39.

Relative Values for Means and Standard Deviations of Milk Yield Recorded by the S.M.R.S. and the English Systems.

	S.M.R.S.	E.S.
Mean actual yield	100	100
Mean recorded yield	105.0364	100.3428
Mean error	5.0364	.3428
Standard deviation of the error	3.5898	.8021
Limits of variation ($M \pm 2\sigma$)	97.8568 - 112.2160	98.7386 - 101.9470
Range of variation	14.3592	3.2084

TABLE 40.

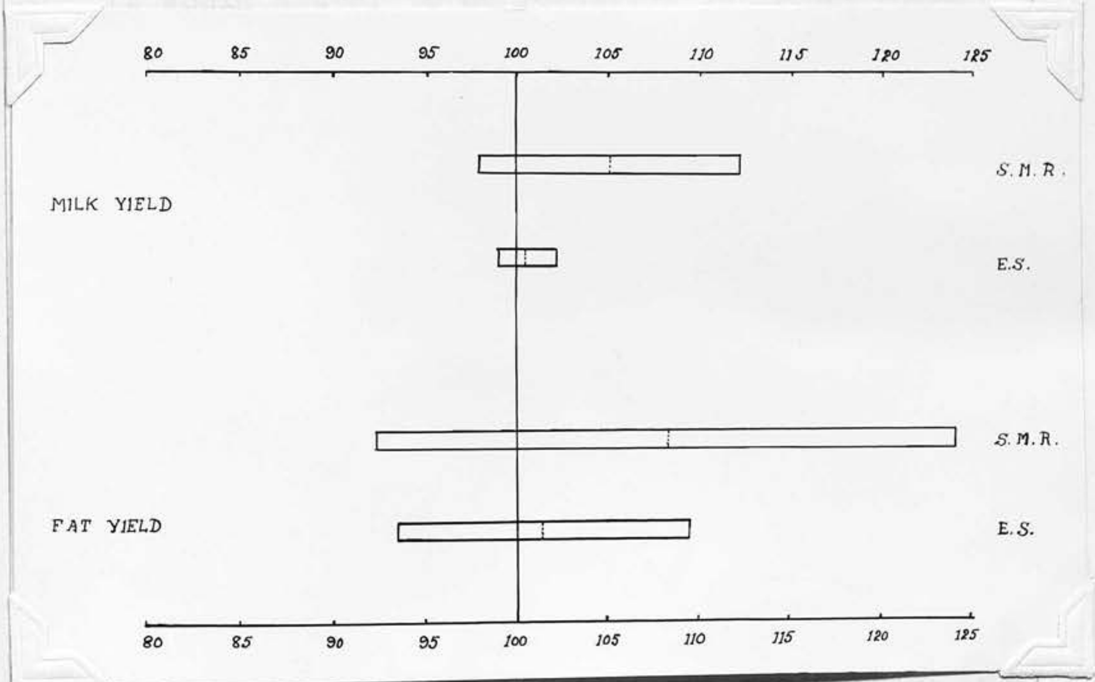
Relative Values for Means and Standard Deviations of Fat Yield Recorded by the S.M.R.S. and the English Systems.

	S.R R.S.	E.S.
Mean yield (Farms' records)	100	100
Mean recorded yield	108.3191	101.4353
Mean error	8.3191	1.4353
Standard deviation of the error	8.0066	3.9821
Limits of variation ($M \pm 2\sigma$)	92.3059 - 124.3323	93.4711 - 109.3995
Range of variation	32.0264	15.9284

with a standard deviation of 3.98% shows that the system adopted in England for estimation of the fat is very reliable. That such a degree of accuracy could be obtained from seven or eight analyses of fat came as quite a surprise, and does suggest methods of cheaper recording than those adopted in many countries.

The results obtained from these tables are further illustrated in Fig.11.

Fig.11. Graphic representation of $M \pm 2\sigma$, i.e. the range of variation in milk and fat yields calculated by the Scottish and the English Systems.



HOW CAN THE SCOTTISH SYSTEM BE IMPROVED?

The Scottish system works out remarkably well in practice and the average error is not too great, but it might, with advantage, be reduced. Moreover, the Scottish error is systematically too high. It is also least accurate when applied to high-yielding cows which are the important ones in a selective breeding policy.

It would appear to be justified to deduce that the error is due, not to the system adopted, which is reasonably accurate, but to the method by which it is put into practice.

The error in the lactation yield of milk appears largely to reside (a) in the fact that the farmer has a pretty shrewd idea when the recorder is likely to visit him, and (b) faulty calculation of the length of the lactation.

The error in fat yield is primarily determined by the error in milk yield, which is magnified, and, secondly, by error in the sampling and analysis of the sample on the part of the recorder.

It is also evident that the accuracy of the work of the different recorders may show considerable variation.

Cost is the prime consideration. If the recorders had smaller circuits and were able more frequently to visit the herds, the errors in milk yield would be reduced/

reduced materially, but even this would not overcome all the sources of error which exist at present. Likewise, if the recorders were better paid, and if they were moved from one circuit to another, the accuracy of the work would be enhanced. It is suggested that, as the Milk Marketing Boards are directly concerned with the lowering of the costs of milk production, the accuracy of the basis for the selection of pedigree dairy stock should be a matter for considerable concern on their part, and that they should contribute towards the cost. Incidentally, accurate recording could furnish the Marketing Boards with a lot of other useful information.

Apart from this, it appears to the author that the existing Scottish system might, with advantage, be improved without necessarily increasing the cost. If farmers were themselves to keep weekly records, then these could be checked at one milking per day at intervals of from 10 to 21 days, averaging say 14. The recorder would only test a complete 24 hours milking on the average every six weeks.

The present system, with a circuit of 24 herds, gives an average interval of 28 days (allowing 4 Sundays off). Assuming that the size of the circuit cannot be reduced, it would be possible for the recorder to test fully 14 herds under the suggested arrangement and to check-test at one milking 20 herds, 10 of which would be/

be ones already visited in the 28-day period: the remaining 10 would be the herds that were not fully tested. In addition, the recorder would not move, as he does at present, on a pre-arranged circuit, but at random amongst the herds in his circuit.

The disadvantages of this arrangement are (a) that the travelling expenses of the recorder would be higher, and (b) that the farmer has to keep weekly records. As regards the lodging and feeding of the recorder, no greater demands would be made upon the farmer's wife than at present - except that she would not receive warning of his coming.

Furthermore, it appears to the author that another source of error in the estimation of the fat yield would be reduced if the recorder could be absolved from the analysis of the fat samples, and if these could be conducted by the Colleges of Agriculture at their laboratories in Glasgow, Auchincruive, Edinburgh and Aberdeen, with, perhaps, additional laboratories at, say, Perth and Inverness. It appears reasonable that the cost of this work should be financed by the Milk Marketing Boards involved since the raising of the quality of the milk is a matter of great importance to the dairy industry generally, and since, in any case, with the new arrangements for the payment of all milk on a butterfat basis, such laboratories, run independently of the distributors, are a necessity.

THE VALUE OF MILK RECORDING.

It is possible that those critics of milk recording (who are now very few) may seize upon these observations of the accuracy of a system as a weapon to use in their argument against redording. They are quite without justification if they do so. This is not the place to emphasize in detail the value of milk recording, without which would have been impossible the improvements which have taken place in the breeds of dairy cattle in all civilized countries. Nor is this the time to emphasize the important future of milk recording when properly applied through the Progeny Test for the selection of bulls or as it emphasizes the necessity for lifetime production in the cows. If artificial insemination becomes, as it is likely to become, a practical proposition, milk recording assumes a place of even greater importance than at present.

Those who would use the facts stated in this paper as an argument against milk recording may be compared to a person who says that artillery should not be used in modern warfare because it is inaccurate. Even if 50% of the shots fired are liable to fall short or over the target, there still remains the devastating effect of the 50% that will strike it. This paper is designed to improve the accuracy of a weapon which already has a high accuracy but the improvement of which accuracy should enable us the better to contend with the invaders of our markets and to take the offensive in the export of pedigree stock.

SUMMARY AND CONCLUSIONS.

Difficulties encountered in systems of Milk Recording and the sources of error in their calculations are discussed.

A review of previous papers was given in detail.

Hitherto, estimates of the accuracy of different systems have been based on a small number of lactations. So far as the author is aware, the accuracy has never been examined of a system in actual operation.

Up to 267 normal lactations of Ayrshire cows made in the herds under the management of the Institute of Animal Genetics form the basis of this study. The accuracy of these records made daily in the case of milk yield, and weekly for fat yield, was found to be high. The mean weekly yield of a sample of cows was found to be 8.706 lbs. of fat with a mean error of - .065 lbs., and a standard deviation of the error amounting to .705. There was no significant correlation between the yield and the error.

Taking the test day in the centre of the test interval, it was found that, with an average lactation yield of milk of 9354 lbs., the mean error for 7, 14, 21 and 28-day test intervals was respectively + 32.0, + 25.4, - 1.7, - 21.3, with standard deviations of the error amounting to 74.96 ± 3.73, 118.10 ± 5.88, 169.80 ± 8.45, and 185.10 ± 9.21: the relative range of/

of variation for the four test intervals was 3.21, 5.05, 7.27 and 7.92 respectively. Tests at 21 and 28 days show little difference, but appreciable increase on tests at 7 and 14 days. However, all test intervals show a high degree of accuracy. No correlation was found to exist between yield and error.

In an examination of the accuracy of fat yield recorded at intervals of 14, 21 and 28 days as compared to the 7-day test used for the farm records, a similarity was again noted between the 21 and 28-day tests, whose errors were of greater magnitude than in the case of the 14-day test, but for any of the test periods the error was not large. On a mean lactation yield of 354 lbs., fat, the relative figures are for 14, 21 and 28-day tests: mean error, - .527, - .667 and -1.930; standard deviation of the error, 6.34 $\pm$ .32, 10.49 $\pm$ .52, and 11.14 $\pm$ .56; relative range of variation, 7.16, 11.85 and 12.58. Correlations between yield and error were not significant.

Examining the accuracy of the official records of the Scottish Milk Records Society, 267 completely normal lactations were available for milk yield, and 248 for fat yield. As differences were noted in the length of the lactations when the Farms' and official records were compared, records by both systems were reduced to the same length. By the farm records the mean yield of milk was found to be 8940 lbs. as against 9391 calcu-

lated/

calculated by the official method. It was found that 252 of the official records showed an increase on the actual yield. The mean error was 5.04%, with a standard deviation of 3.59, and a maximum error of 36.5%.
A positive correlation of + .283 ± .056 was obtained between yield and error.

For fat yield, the error was greater, due in part to errors in estimation of the fat yield itself, but also largely to the error in milk yield noted. For complete lactation, the farms' records gave a mean yield of 333 lbs. as against 361 lbs. by the official records: in 218 out of 248 lactations, the official exceeded the farm records. The mean error was 8.32% with a standard deviation of 8.01. The error exceeded 10% in 98 lactations, or 39.5% of all recorded.
A small positive correlation of .194 ± .06 was found between yield and error.

Method of the sampling of the butterfat by the official method is discussed.

In fat percentage the average excess of the official over the farms' records amounted to .13%, with an extreme case of .75%.

Comparing the length of the lactation period of the official with the farms' records over 50% of the official records showed an excess of at least two weeks. This error is not circulated in the foregoing.

Notes are given of the accuracy of the work of different/

different recorders employed by the Scottish Milk Records Association, which is shown to vary appreciably.

The effect of the error on the selection of high-yielding cows is dealt with: in these, the absolute error is the greatest: the records of these cows are the ones of major importance to the constructive breeder.

Analysis is made of the interesting system of milk recording employed in England, where the onus of the milk yield records and their accuracy absolutely depends on the farmer or cattleman. Butterfat is tested every 6-8 weeks. If the milk records are accurate, then there is a high degree of accuracy in the English system of recording fat yield. No significant correlation was found between fat yield and error.

A comparison of the Scottish and English Systems of recording was given.

The discussion includes suggestions on how the Scottish system might be improved. More accurate determination of milk yield is desirable, and it is considered that greater accuracy would be achieved if the fat samples were analysed under standard conditions and some central laboratories.

The paper concludes with a note on the value of milk recording, and that critics of milk recording should not use the results obtained in this investigation as an argument against milk recording.

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PART II.

THE RELATIVE ACCURACY OF INDIVIDUAL RECORDS AND COMBINATIONS OF RECORDS IN EVALUATING THE PRODUCING ABILITY OF DAIRY COWS.

CONTENTS.

LIST OF FIGURES.

INTRODUCTION.

Since the best estimate of the producing ability of a cow can be obtained from the average of several lactation yields, it is natural that great stress should be laid upon this value in selection and genetic studies.

A cow with a high average yield taken from as many lactations as possible deserves the breeder's attention as she represents the type of animal on which he should base his selection and genetical improvement. Unfortunately by the time such a cow has completed a sufficient number of lactations and has proved her worth as a profitable dairy animal, there may not be many of her progeny available. Moreover, in evaluating a bull, it is too long to wait till lifetime yields are available for a sufficient number of his daughters.

In view of these facts, it appears that the most satisfactory method of solving this problem is to study the relationship between different lactations of the same cow, and their correlations with the lifetime average yield (taking 5 lactations as a standard lifetime/

lifetime). From this may be determined the relative accuracy of different lactations or combinations of these as indices of the milking capacity of a cow. By transferring the degrees of relationship to measurable values a scale could be provided which will enable the breeder to evaluate his animals from one or a limited number of lactations.

PREVIOUS INVESTIGATIONS AND THEIR RESULTS.

As far as the writer is aware, COPELAND (1938) is the only worker who has attacked the problem on the above lines. He studied the Register of Merit and Herd Improvement Registry records of 197 Jersey cows which had completed five or more 305 or 365 day Register of Merit records. The method he used was as follows:

First, each record completed by each cow was converted to a mature 365-day equivalent basis, using the age conversion factors tabulated by the American Jersey Cattle Club. Then the correlation between the first and second records was determined. Similarly, the correlation coefficients were determined between the second and third, the third and fourth, and the fourth and fifth record for each cow.

Next, a comparison was made between the first record completed by each cow and the average of her next/

next four records. In addition, correlations were tabulated between the first record and the average of all five records, and lastly the highest record of each cow was compared with the average of all five records. The results obtained are shown in Table 1.

In a further study, exactly the same comparisons were made using 166 cows that had finished five or more consecutive complete Herd Test lactations. The results are given in Table 2.

In most instances the correlation coefficients given in Table 2 are a little higher than the corresponding ones in Table 1. This is not unexpected, for most Herd Test records are made on a lower level of production than Register of Merit records, and this naturally tends to reduce the variation from individual records. This reduction in variation may tend to increase the correlations.

COPELAND, however, states that the correlation between the highest record completed and the average of all five records is extremely high and indicates that the highest record completed by any cow gives a very good estimate of her lifetime average, provided she is kept on test continuously and encounters no disease or misfortune. He adds that all of the coefficients of correlation are very good, indicating a relatively high degree of repeatability between normal records made by the same cow.

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TABLE 1.

Correlation coefficients between records made by the same cow
(197 cows with 5 or more R. of M. records used)

Comparisons and correlations made.	Coefficient of correlation.
Comparison of 1st R. of M. record with 2nd record	+ 0.71 ± .024
Comparison of 2nd R. of M. record with 3rd record	+ 0.77 ± .020
Comparison of 3rd R. of M. record with 4th record	+ 0.69 ± .025
Comparison of 4th R. of M. record with 5th record	+ 0.59 ± .031
Comparison of 1st R. of M. record with the average of next four records	+ 0.62 ± .030
Comparison of 1st R. of M. record with average of all five records	+ 0.75 ± .021
Comparison of highest R. of M. with average of all five records	+ 0.92 ± .007

TABLE 2.

Correlation coefficient between consecutive Herd Test records made by the same cow
(166 cows with 5 or more Herd Test records used)

Comparisons and correlations made.	Coefficient of correlation.
Comparison of 1st Herd Test record with 2nd record	+ 0.78 $\pm$ .021
Comparison of 2nd Herd Test record with 3rd record	+ 0.80 $\pm$ .019
Comparison of 3rd Herd Test record with 4th record	+ 0.75 $\pm$ .023
Comparison of 4th Herd Test record with 5th record	+ 0.83 $\pm$ .016
Comparison of 1st Herd Test record with average of next four records	+ 0.80 $\pm$ .019
Comparison of 1st Herd Test record with average of all five records	+ 0.88 $\pm$ .012
Comparison of highest Herd Test record with average of all five records	+ 0.92 $\pm$ .008

The work of COPELAND is a valuable contribution to animal breeding, but his study is limited and exception might be taken to a few points in his method. In the first place, the application of conversion factors is not advisable as it is only justifiable when all cows are kept under the some environmental conditions and methods of husbandry. Also by applying these factors another source of error has been introduced.

The data used in his study consist of butterfat records only and these are liable to show greater variation than those for milk yield, as they include the error involved in the estimation of the fat percentage in the milk.

It is particularly important to note that COPELAND'S data are derived from several forms and that variation in management and environment affects the results given. No allowance has been made for this and the present writer hopes to demonstrate that this variation is highly significant.

It appears that COPELAND could profitably have extended his study to determine the relative accuracy of the different lactations and the average of two, three or more records as indices of the cow's hereditary milking capacity, as it would be of great value to the breeder if he could be given a scale on which to build when his knowledge of an animal's production is limited.

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The present investigation has been carried out with the view of supplementing the work of COPELAND.

MATERIAL.

The data for the present investigation were derived from the official books of the Scottish Milk Records Association for the years 1925 to 1937. Records were taken from 21 pure Ayrshire herds, and after excluding animals which for any reason were not recorded for a part of their lifetime, or which failed to calve within a reasonable period, a number of 225 cows which had completed five or more normal and consecutive lactations was available. Five lactations were taken for each cow, to represent her lifetime yield.

Milk and fat records were analysed separately and on the same lines.

RESULTS AND DISCUSSION.

MILK YIELD.

Means, standard deviations and coefficients of variation were calculated for the separate lactations, the average of the five lactations, and for the highest record completed by each cow. The results are given in/

in Table 3. It will be observed that the most variable lactation yields are the first and the fifth, while the least are the fourth and second.

If 8703 lbs, the mean of the first lactation yields, is taken as 100, the relative values for means of different lactations and standard deviations are obtained. The results are given in Table 4 and shown graphically in Fig 1.

Relation between records of the same cow.

In analysing the records it was first attempted to determine the relation between the different lactations. The correlation was calculated between the first lactation yield and each of the subsequent, and similarly, that between the second, the third and the fourth and each of the subsequent lactation yields. The results are shown in Table 5.

These comparisons show that each record is most highly correlated with the one which follows or precedes it, the greatest correlation existing between the third and fourth. The relation between any two records tends to decrease with the increase of period between them, as the longer the elapsed time the greater is the possibility that events may take place which will affect the yield of one record as compared with the other.

It/

TABLE 3.

Means, standard deviations and coefficients of variation for the different lactations.

Different lactations	Mean ± Standard error	Standard deviation ± Standard error	Coefficient of variation.
First lactation	8703 ± 110.2 lbs.	1653 ± 78.0 lbs.	18.99
Second lactation	8950 ± 100.3 "	1505 ± 71.0 "	16.82
Third lactation	9530 ± 109.5 "	1643 ± 77.5 "	17.24
Fourth lactation	9779 ± 108.1 "	1621 ± 76.5 "	16.58
Fifth lactation	10073 ± 123.3 "	1849 ± 87.2 "	18.36
Highest lactation	10829 ± 120.8 "	1812 ± 85.5 "	16.73
Average of the five lactations	9392 ± 91.2 "	1368 ± 64.5 "	14.57

TABLE 4

Relative values for means and standard deviations of different lactation yields.

Different lactations	Mean	Standard deviation
First lactation	100.00	18.99
Second lactation	102.84	17.29
Third lactation	109.50	18.88
Fourth lactation	112.36	18.63
Fifth lactation	115.75	21.25
Highest lactation	124.42	20.82
Average of all the five lactations	107.92	15.72

FIG. 1.

Increase of milk yield with age.

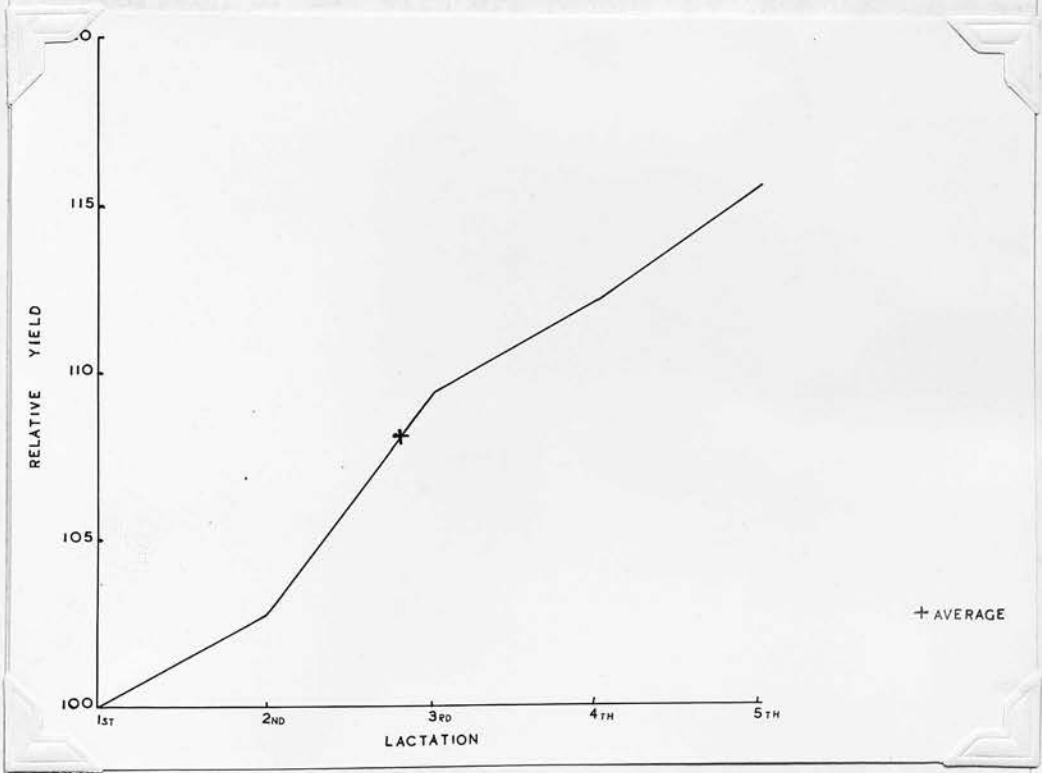

TABLE 5.

Correlation coefficients between records made by the same cow.

Comparisons of lactations	Correlation coefficients.
Comparison of 1st with 2nd record	+ .688 ± .035
Comparison of 1st with 3rd record	+ .595 ± .043
Comparison of 1st with 4th record	+ .529 ± .048
Comparison of 1st with 5th record	+ .426 ± .055
Comparison of 2nd with 3rd record	+ .715 ± .033
Comparison of 2nd with 4th record	+ .621 ± .041
Comparison of 2nd with 5th record	+ .543 ± .047
Comparison of 3rd with 4th record	+ .729 ± .031
Comparison of 3rd with 5th record	+ .590 ± .043
Comparison of 4th with 5th record	+ .627 ± .040

It will be observed that the correlations between the first and the fifth lactations and the other lactations are comparatively low. The fact that these two lactations are most variable (Table 3) might tend to lower their degree of relationship with any other record and with each other.

The great variation which occurs in the first lactation is probably largely dependant on age at first calving and early maturity. Variation in the fifth lactation can be more correctly attributed to the influence of diseases on the mammary gland.

Frequently a cow may meet with some mishap while being tested and sometimes one which has completed one good record has not been tested again. Such cows should not be neglected as they might have been quite useful to the breed if they had been more fortunate. For this reason it was decided to express the degree of relationship between different records made by the same cow in a measurable value. This was done through the calculation of the regression coefficients which are given in Table 6.

A record which is missing or abnormal can by the use of the following regression equation be calculated if any of the other lactation yields made by the same cow is known.

$$E = \bar{y} + b\ (X - \bar{x})$$

in which:

E /

TABLE 6.

Regression coefficients for different lactations made by the same cow.

Different lactations	Regression coefficients
Regression coefficient of second record on first	+ .627
Regression coefficient of third record on first	+ .591
Regression coefficient of fourth record on first	+ .519
Regression coefficient of fifth record on first	+ .477
Regression coefficient of third record on second	+ .780
Regression coefficient of fourth record on second	+ .669
Regression coefficient of fifth record on second	+ .667
Regression coefficient of fourth record on third	+ .719
Regression coefficient of fifth record on third	+ .664
Regression coefficient of fifth record on fourth	+ .715

E = the yield during the missing or abnormal lactation.

$\bar{y}$ = the mean value for this lactation (Table 3)

b = the regression coefficient of the missing record on the known one (Table 6)

X = the actual value of the known record.

$\bar{x}$ = the mean value for this known record (Table 3)

Relation between individual records and the lifetime average yield of the same cow.

The next step was to determine the relative accuracy of different lactations as indicators of the producing ability of a cow. This was done by taking the average of the five records made by each cow and correlating this with each of the lactations and with the highest completed record. The results are given in Table 7.

All the correlation coefficients are very high, showing that the average yield of a cow may be estimated with a considerable accuracy from any of her individual records. The correlation between the highest record and the average of all five lactations is extremely high, demonstrating that the highest record completed by a cow gives the best estimate of her lifetime average. That the highest record should be most highly correlated with the average is to be expected as it contributes more to that value.

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TABLE 7.

Correlation coefficient between individual records and lifetime average yield of the same cow.

Correlations made	Correlation Coefficients
Relation between 1st record and the average of all five records	+.770 ± .027
Relation between 2nd record and the average of all five records.	+.845 ± .019
Relation between 3rd record and the average of all five records	+.869 ± .016
Relation between 4th record and the average of all five records	+.843 ± .019
Relation between 5th record and the average of all five records	+.781 ± .026
Relation between highest record and the average of all five records	+.895 ± .013

Since, however, the point when the cow reaches her maximum record cannot be definitely known, it is suggested that in selection, great importance should be attached to the third or second lactation, as these are also highly correlated with the average.

Although the first lactation is of necessity widely used in progeny testing and selection, it was shown (Table 7) to be the least accurate for estimating the value of a cow.

For calculating the lifetime average yield from individual records the regression coefficients of the average on the different lactations were calculated and are given in Table 8. The regression equation to be used in such estimations is as follows:

$$E = \bar{y} + b\,(X - \bar{x})$$

in which

E = the average of the five lactation yields

$\bar{y}$ = the mean value for this average (Table 3)

b = the regression coefficient of the average on the known record (Table 8)

X = the actual value of the known record

$\bar{x}$ = the mean value of this known record (Table 3)

Effect of herd.

As the data studied have been derived from several herds, it was considered desirable to test whether or not the influence of the herd is significant.

The/

TABLE 8.

Regression coefficients of the average of five records on the different lactation yields by the same cow.

Regressions on different lactations	Regression coefficients
Regression coefficient of the average of five records on the first	+ .637
Regression coefficient of the average of five records on the second	+ .768
Regression coefficient of the average of five records on the third	+ .723
Regression coefficient of the average of five records on the fourth	+ .711
Regression coefficient of the average of five records on the fifth	+ .578
Regression coefficient of the average of five records on the highest	+ .675

The analysis of variance was carried out and the results are shown in Table 9. It will be observed that the values of F (ratio between the mean square between herds and that within herds) are all over 2.2, which is the figure given by SNEDECOR for 1% P in the case of 12 and 200 degrees of freedom.

The lactation yields are therefore significantly differentiated from one herd to another, which suggests that a part of the total correlations already calculated might have arisen from the fact that in a good herd all the five records of the same cow and their average are likely to be comparatively high, while in a bad herd they are likely to be low.

In order to eliminate this part of the correlations, the correlation coefficients were again calculated, this time within herds, by means of analysis of covariance. The analysis of covariance gave the results shown in Table 10.

Table 11 contains the correlation coefficients within herds and their standard error. Comparing these correlations with the corresponding values in Table 5 and Table 7 it is seen that the elimination of the effect of herd has reduced the correlations.

The regression coefficients of the different lactations and the average were established and are given in Table 12. These latter regressions are those which should be used by a breeder who is concerned only with influences within his herd.

The/

TABLE 9.

Analysis of variance in milk yield.

Lactation		D/F	Mean square	F
First	Total	224	2731403	
	Between herds	20	5370207	2.2
	Within herds	204	2472697	
Second	Total	224	2266442	
	Between herds	20	8560047	5.2
	Within herds	204	1649422	
Third	Total	224	2698693	
	Between herds	20	10354379	5.3
	Within herds	204	1948136	
Fourth	Total	224	2627374	
	Between herds	20	7406961	3.4
	Within herds	204	2158787	
Fifth	Total	224	3417555	
	Between herds	20	11651570	4.5
	Within herds	204	2610299	
Highest	Total	224	3284994	
	Between herds	20	13063121	5.6
	Within herds	204	2326354	
Average of 5 records	Total	224	1870263	
	Between herds	20	8161646	6.5
	Within herds	204	1253461	

TABLE 10.

Analysis of covariance in milk yield.

Lactations		D/F	Sum of products
First and second	Total	224	383418900
	Between herds	20	163255500
	Within herds	204	220163400
First and third	Total	224	361735200
	Between herds	20	147948600
	Within herds	204	213786600
First and fourth	Total	224	317594400
	Between herds	20	126067600
	Within herds	204	191526800
First and fifth	Total	224	291697800
	Between herds	20	123000200
	Within herds	204	168697600
Second and third	Total	224	395829500
	Between herds	20	162183900
	Within herds	204	233645600
Second and fourth	Total	224	339444200
	Between herds	20	142516500
	Within herds	204	196927700
Second and fifth	Total	224	338395400
	Between herds	20	152146200
	Within herds	204	186249200
Third and fourth	Total	224	434558400
	Between herds	20	160916600
	Within herds	204	273641800
Third and fifth	Total	224	401690500
	Between herds	20	173998300
	Within herds	204	227692200
Fourth and fifth	Total	224	420644000
	Between herds	20	152339100
	Within herds	204	268304900

TABLE 10 (continued)

Analysis of covariance in milk yield.

Lactations		D/F	Sum of products
Average and first	Total	224	389919400
	Between herds	20	152646400
	Within herds	204	237273000
Average and second	Total	224	389691300
	Between herds	20	161181000
	Within herds	204	228510300
Average and third	Total	224	437177900
	Between herds	20	171805200
	Within herds	204	265372700
Average and fourth	Total	224	418497200
	Between herds	20	148506600
	Within herds	204	269990600
Average and fifth	Total	224	442129800
	Between herds	20	169772600
	Within herds	204	272357200
Average and highest	Total	224	496832800
	Between herds	20	197491500
	Within herds	204	299341300

TABLE 11.

Correlation coefficients between records made by the same cow (calculated within herds)

Different lactations	Correlation coefficients.
Correlation between 1st and 2nd record	+ .534 ± .050
Correlation between 1st and 3rd record	+ .477 ± .054
Correlation between 1st and 4th record	+ .406 ± .059
Correlation between 1st and 5th record	+ .325 ± .063
Correlation between 2nd and 3rd record	+ .639 ± .041
Correlation between 2nd and 4th record	+ .512 ± .052
Correlation between 2nd and 5th record	+ .440 ± .057
Correlation between 3rd and 4th record	+ .654 ± .040
Correlation between 3rd and 5th record	+ .495 ± .053
Correlation between 4th and 5th record	+ .554 ± .049
Correlation between 1st record and the average	+ .661 ± .040
Correlation between 2nd record and the average	+ .779 ± .028
Correlation between 3rd record and the average	+ .832 ± .022
Correlation between 4th record and the average	+ .804 ± .025
Correlation between 5th record and the average	+ .738 ± .032
Correlation between highest record and the average	+ .860 ± .018

TABLE 12.

Regression coefficients for different records made by the same cow
(calculated within herds)

Different lactations	Regression coefficients
Regression coefficient of 2nd record on 1st	+ .436
Regression coefficient of 3rd record on 1st	+ .424
Regression coefficient of 4th record on 1st	+ .380
Regression coefficient of 5th record on 1st	+ .334
Regression coefficient of 3rd record on 2nd	+ .694
Regression coefficient of 4th record on 2nd	+ .585
Regression coefficient of 5th record on 2nd	+ .554
Regression coefficient of 4th record on 3rd	+ .689
Regression coefficient of 5th record on 3rd	+ .573
Regression coefficient of 5th record on 4th	+ .609
Regression coefficient of the average on the 1st	+ .470
Regression coefficient of the average on the 2nd	+ .679
Regression coefficient of the average on the 3rd	+ .668
Regression coefficient of the average on the 4th	+ .613
Regression coefficient of the average on the 5th	+ .511
Regression coefficient of the average on the highest	+ .631

The elimination of herd differences also reduces the standard deviation for the different lactations. These were found to be as shown in Table 13.

Estimation of the lifetime average when more than one lactation yield are available.

The fact that two or more records may furnish a better index of the milking capacity of a cow makes it desirable to calculate the partial regressions of the average on the first and second lactations, the first and third, the second and third, and finally, on the first, second and third lactations.

Taking m_1, m_2, m_3, m_4 and m_5 to indicate respectively the milk yields during the five lactation, and M the average of all five, the regression equations are as follows:

$$M = .244\ m_1 + .520\ m_2 \pm 2614$$

$$M = .244\ m_1 + .537\ m_3 \pm 2151$$

$$M = .365\ m_2 + .453\ m_3 \pm 1808$$

$$M = .175\ m_1 + .282\ m_2 + .408\ m_3 \pm 1457$$

These partial regressions were calculated within herds and therefore the given equations will enable the breeder to estimate the lifetime average for a cow which has given more than one record. It is seen that in every case where the third lactation enters, it has the largest regression coefficient, indicating that/

TABLE 13.

Standard deviations of different lactations (calculated within herds)

Different lactations	Standard Deviation ± Standard error
First lactation	1572 lbs ± 77.8
Second lactation	1284 " ± 63.6
Third lactation	1396 " ± 69.1
Fourth lactation	1469 " ± 72.7
Fifth lactation	1616 " ± 80.0
Highest lactation	1525 " ± 75.5
Average of all the five lactations	1120 " ± 55.4

that this lactation has the greatest influence in determining the lifetime yield.

The standard errors involved in estimating the average of the five records from one or more lactations were calculated and were found to be as follows:

error of 840 lbs when the average is estimated by 1st lactation.

" " 706 " " " " is estimated by 2nd lactation.

" " 627 " " " " is estimated by 3rd lactation

" " 672 " " " " is estimated by 4th lactation.

" " 762 " " " " is estimated by 5th lactation.

" " 571 " " " " is estimated by highest lactation.

" " 622 " " " " is estimated by 1st & 2nd lactations.

" " 522 " " " " is estimated by 1st & 3rd lactations.

" " 506 " " " " is estimated by 2nd & 3rd lactations.

" " 452 " " " " is estimated by 1st, 2nd & 3rd lactations.

Naturally, as more lactations are introduced into the regressions the error involved in the estimation diminished, but the error for the regression based on the third lactation alone is almost the same as that based on the first and second lactations together.

FAT YIELD.

The investigations for fat yield were carried out in the same manner as for milk. Means, standard deviations and coefficients of variation were determined and the results are given in Table 14. For the same reason as mentioned in the case of milk yield, great variation was found in the first and fifth lactations, while there was less variation in the third and fourth. Comparing the coefficients of variation for fat yield with the corresponding figures for milk (Table 3), it could be noted that in general fat yield is more variable. This is probably due to the additional source of variation introduced by the error of estimating the butterfat percentage.

Taking the mean value for the first lactation, viz. 349 lbs, as = 100, the relative values for means of different lactations and their standard deviations were calculated and are shown in Table 15. A graphical representation of the relative means is given in Fig.2.

To facilitate comparison between the curves for milk and fat yields, they have been drawn on the same scale in Fig.3. It will be observed that the increase in the yield from one lactation to another is more pronounced in the case of milk than in the case of fat yield.

TABLE 14.

Means, standard deviations and coefficient of variation for the different lactations.

Different lactations	Mean $\pm$ standard error	Standard deviation $\pm$ Standard error	Coefficient of variation
First lactation	349.0 $\pm$ 4.4 lbs.	65.9 $\pm$ 3.1 lbs	18.88
Second lactation	353.2 $\pm$ 4.3 "	63.9 $\pm$ 3.0 "	18.09
Third lactation	375.2 $\pm$ 4.4 "	66.3 $\pm$ 3.1 "	17.67
Fourth lactation	383.7 $\pm$ 4.3 "	64.4 $\pm$ 3.0 "	16.78
Fifth lactation	393.0 $\pm$ 5.0 "	74.3 $\pm$ 3.5 "	18.91
Highest lactation	429.3 $\pm$ 4.9 "	73.6 $\pm$ 3.5 "	17.14
Average of all the five lactations	370.5 $\pm$ 3.5 "	53.1 $\pm$ 2.5 "	14.33

TABLE 15.

Relative values for means and standard deviations of different lactation yields.

Different lactations	Mean	Standard deviation
First lactation	100.00	18.88
Second lactation	101.20	18.31
Third lactation	107.51	19.00
Fourth lactation	109.94	18.45
Fifth lactation	112.61	21.29
Highest lactation	123.01	21.09
Average of all the five lactations	106.16	15.22

FIG. 2.

Increase of fat yield with age.

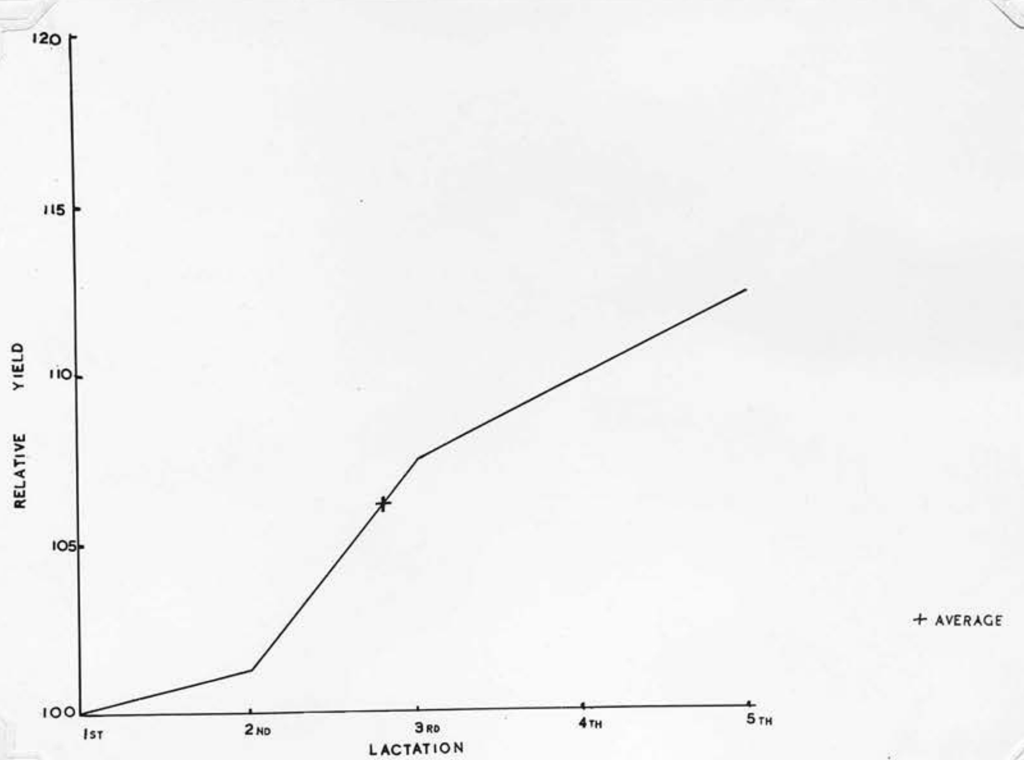
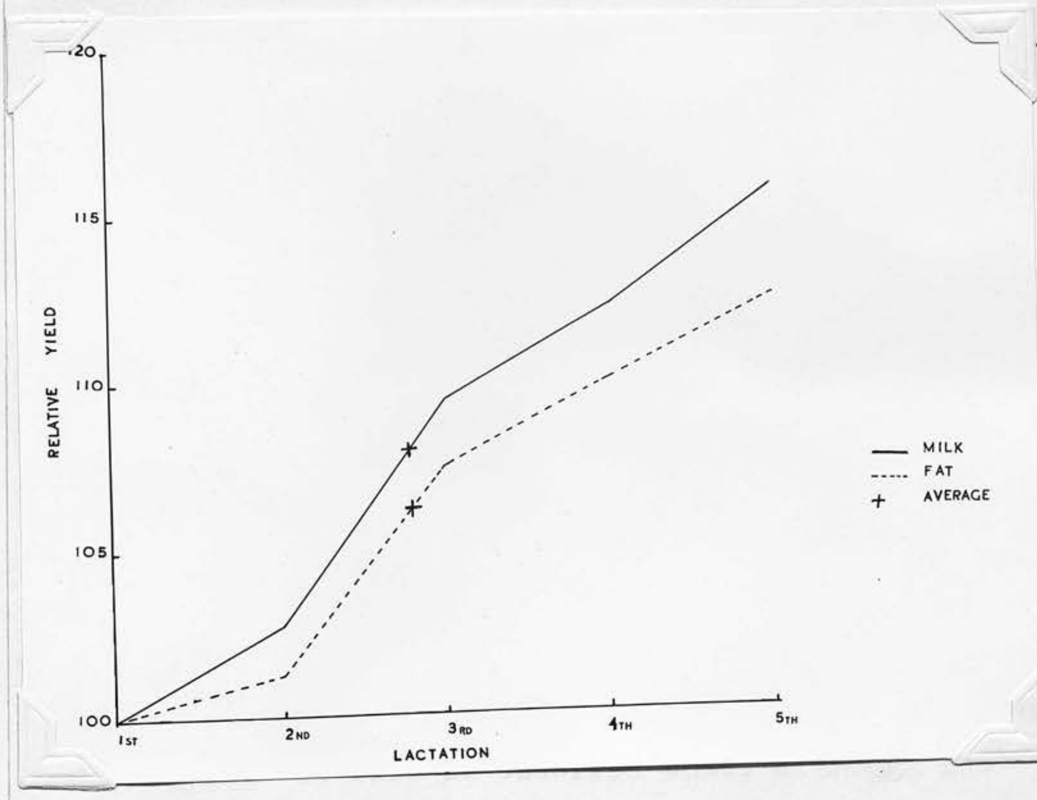


FIG. 3.

Increase of milk and fat yields with age.



Relation between records of the same cow.

The correlation coefficients between the different lactations of the same cow were estimated and Table 16 was compiled to give the values obtained. These are lower than the corresponding values for milk yield, presumably because fat yield is more variable, but comparison with Table 5 reveals a close similarity in the relationship between the different records.

The degree of relationship between individual lactation yields was then expressed in measurable values by means of the regression coefficients. These are given in Table 17.

Relation between individual records and the lifetime average of the same cow.

Correlations were calculated between individual lactations, as well as the highest yield, and the average of the five records. The results are shown in Table 18. It will be observed that, although the correlations for fat are in general lower than those for milk yield (Table 7), they still indicate a strong relationship between any one of the lactations and the lifetime average. The highest correlations exist between the highest record and the average and the third lactation and the average, while the lowest are those between the first and average and fifth and average.

The/

TABLE 16.

Correlation coefficients between records made by the same cow.

Comparisons of lactations	Correlation coefficients
Comparison of 1st with 2nd record	+ .644 ± .039
Comparison of 1st with 3rd record	+ .548 ± .047
Comparison of 1st with 4th record	+ .450 ± .053
Comparison of 1st with 5th record	+ .314 ± .060
Comparison of 2nd with 3rd record	+ .697 ± .034
Comparison of 2nd with 4th record	+ .570 ± .045
Comparison of 2nd with 5th record	+ .434 ± .054
Comparison of 3rd with 4th record	+ .675 ± .036
Comparison of 3rd with 5th record	+ .491 ± .051
Comparison of 4th with 5th record	+ .572 ± .045

TABLE 17.

Regression coefficients for different lactations made by the same cow.

Different lactations	Regression coefficients
Regression coefficient of second record on first	+ .624
Regression coefficient of third record on first	+ .551
Regression coefficient of fourth record on first	+ .440
Regression coefficient of fifth record on first	+ .354
Regression coefficient of third record on second	+ .723
Regression coefficient of fourth record on second	+ .574
Regression coefficient of fifth record on second	+ .505
Regression coefficient of fourth record on third	+ .657
Regression coefficient of fifth record on third	+ .551
Regression coefficient of fifth record on fourth	+ .660

TABLE 18.

Correlation coefficient between individual records and lifetime average yield of the same cow.

Correlations made	Correlation coefficients
Relation between 1st record and the average of all five records	+ .721 ± .032
Relation between 2nd record and the average of all five records	+ .830 ± .021
Relation between 3rd record and the average of all five records	+ .856 ± .018
Relation between 4th record and the average of all five records	+ .821 ± .022
Relation between 5th record and the average of all five records	+ .751 ± .029
Relation between highest record and the average of all five records	+ .888 ± .014

The conclusions to be drawn are similar to those noted in the study of milk yield.

Table 19 contains the regression coefficients of the average of the five lactations on each record. By means of the regression equations the lifetime average fat yield of a cow may be assessed when she has completed one or more records.

Effect of herd.

Analysis of variance was carried out as for milk yield and the results obtained are given in Table 20. The values for F show that fat yield during any one of the lactations varies significantly with the change of herds, so that in this case it was again necessary to estimate the correlations and regressions within herds by means of analysis of covariance. The results are tabulated in Table 21.

Table 22 gives the correlation coefficients calculated within herds. These correlations show lower values than the corresponding ones in Table 16 and Table 18. As has already been indicated in the case of milk yield, this must be attributed to the fact that in a particular herd various causes are likely to affect the different lactations and their averages for the same cow and in the same way.

The regression coefficients for the different lactations and the average were determined (Table 23). The/

TABLE 19.

Regression coefficients of the average of five records on the different lactation yields of the same cow.

Regressions on different lactations	Regression coefficients
Regression coefficient of the average of five records on the first	+ .581
Regression coefficient of the average of five records on the second	+ .690
Regression coefficient of the average of five records on the third	+ .686
Regression coefficient of the average of five records on the fourth	+ .677
Regression coefficient of the average of five records on the fifth	+ .537
Regression coefficient of the average of five records on the highest	+ .641

TABLE 20.

Analysis of variance in fat yield.

Lactation		D/F	Mean square.	F
First	Total Between herds Within herds	224 20 204	4345 18467 2961	6.2
Second	Total Between herds Within herds	224 20 204	4086 13039 3208	4.1
Third	Total Between herds Within herds	224 20 204	4389 17543 3099	5.3
Fourth	Total Between herds Within herds	224 20 204	4152 12846 3299	3.9
Fifth	Total Between herds Within herds	224 20 204	5524 20729 4033	5.2
Highest	Total Between herds Within herds	224 20 204	5413 23073 3681	6.3
Average of 5 records	Total Between herds Within herds	224 20 204	2822 13567 1768	7.6

TABLE 21.

Analysis of covariance in fat yield.

Lactations		D/F	Sum of products
First and second	Total	224	607637
	Between herds	20	279407
	Within herds	204	328230
First and third	Total	224	535975
	Between herds	20	272164
	Within herds	204	263811
First and fourth	Total	224	428627
	Between herds	20	234469
	Within herds	204	194158
First and fifth	Total	224	344230
	Between herds	20	222127
	Within herds	204	122103
Second and third	Total	224	661472
	Between herds	20	249136
	Within herds	204	412336
Second and fourth	Total	224	525791
	Between herds	20	207968
	Within herds	204	317823
Second and fifth	Total	224	462347
	Between herds	20	206510
	Within herds	204	255837
Third and fourth	Total	224	645678
	Between herds	20	274992
	Within herds	204	370686
Third and fifth	Total	224	541528
	Between herds	20	293965
	Within herds	204	247563
Fourth and fifth	Total	224	613766
	Between herds	20	265635
	Within herds	204	348131
Average and first	Total	224	565870
	Between herds	20	277007
	Within herds	204	288863

Table 21 (continued)

Analysis of covariance in fat yield.

Lactations		D/F	Sum of products
Average and second	Total	224	631431
	Between herds	20	242338
	Within herds	204	389093
Average and third	Total	224	674754
	Between herds	20	290890
	Within herds	204	383864
Average and fourth	Total	224	629562
	Between herds	20	250472
	Within herds	204	379090
Average and fifth	Total	224	664086
	Between herds	20	283938
	Within herds	204	380148
Average and highest	Total	224	777733
	Between herds	20	336584
	Within herds	204	441149

TABLE 22.

Correlation coefficients between records of the same cow (calculated within herds)

Different lactations	Correlation coefficient
Correlation between 1st and 2nd record	+ .522 ± .051
Correlation between 1st and 3rd record	+ .427 ± .057
Correlation between 1st and 4th record	+ .305 ± .064
Correlation between 1st and 5th record	+ .173 ± .068
Correlation between 2nd and 3rd record	+ .641 ± .041
Correlation between 2nd and 4th record	+ .479 ± .054
Correlation between 2nd and 5th record	+ .349 ± .062
Correlation between 3rd and 4th record	+ .569 ± .047
Correlation between 3rd and 5th record	+ .343 ± .062
Correlation between 4th and 5th record	+ .468 ± .055
Correlation between 1st record and the average	+ .619 ± .043
Correlation between 2nd record and the average	+ .800 ± .025
Correlation between 3rd record and the average	+ .803 ± .025
Correlation between 4th record and the average	+ .769 ± .029
Correlation between 5th record and the average	+ .697 ± .036
Correlation between highest record and the average	+ .847 ± .020

TABLE 23.

Regression coefficients for different records of the same cow (calculated within herds)

Different lactations	Regression coefficients
Regression coefficient of 2nd record on 1st	+ .543
Regression coefficient of 3rd record on 1st	+ .437
Regression coefficient of 4th record on 1st	+ .321
Regression coefficient of 5th record on 1st	+ .202
Regression coefficient of 3rd record on 2nd	+ .630
Regression coefficient of 4th record on 2nd	+ .486
Regression coefficient of 5th record on 2nd	+ .391
Regression coefficient of 4th record on 3rd	+ .586
Regression coefficient of 5th record on 3rd	+ .392
Regression coefficient of 5th record on 4th	+ .517
Regression coefficient of the average on the 1st	+ .478
Regression coefficient of the average on the 2nd	+ .595
Regression coefficient of the average on the 3rd	+ .607
Regression coefficient of the average on the 4th	+ .563
Regression coefficient of the average on the 5th	+ .462
Regression coefficient of the average on the highest	+ .587

The breeder should base his estimations on these latter figures as they have been calculated within herds.

The elimination of the effect of herd has also affected the standard deviations already given in Table 14. Those calculated within herds were found to be as shown in Table 24.

<u>Estimation of the lifetime average when more than one lactation yield are available.</u>

The partial regressions of the average of the five records on the first and second lactations, the first and third, the second and third and lastly, on the first, second and third lactations were established.

If f_1, f_2, f_3, f_4 and f_5 be taken to represent the yield during the five lactations respectively, and F the average of all five lactations, the regression equations obtained are as follows:

$$F = .214 f_1 + .488 f_2 + 124$$

$$F = .261 f_1 + .498 f_3 + 93$$

$$F = .360 f_2 + .372 f_3 + 104$$

$$F = .180 f_1 + .277 f_2 + .341 f_3 + 83$$

It will be observed from the values of these regressions that the third lactation plays the greatest part in determining the lifetime average of a cow, - a conclusion which has also been drawn in the case of milk yield.

The/

TABLE 24.

Standard deviations of different lactations
(calculated within herds)

Different lactations	Standard deviation $\pm$ Standard error.
First lactation	54.4 lbs $\pm$ 2.7
Second "	56.6 " $\pm$ 2.8
Third "	55.7 " $\pm$ 2.8
Fourth "	57.4 " $\pm$ 2.8
Fifth "	63.5 " $\pm$ 3.1
Highest "	60.7 " $\pm$ 3.0
Average of all the five lactations	42.1 " $\pm$ 2.1

The standard errors involved in estimating the average of the five records from one or more lactations were found to be as follows:

error of	33.3	lbs when the average	is estimated by 1st lactation.
" "	25.3	" " " "	is estimated by 2nd lactation.
" "	25.3	" " " "	is estimated by 3rd lactation.
" "	26.9	" " " "	is estimated by 4th lactation.
" "	30.3	" " " "	is estimated by 5th lactation.
" "	22.3	" " " "	is estimated by highest lactation.
" "	23.2	" " " "	is estimated by 1st & 2nd lactations.
" "	21.6	" " " "	is estimated by 1st & 3rd lactations.
" "	19.6	" " " "	is estimated by 2nd & 3rd lactations.
" "	18.0	" " " "	is estimated by 1st, 2nd and 3rd lactations.

It will be observed that the error decreases as more lactations are introduced into the regression. The regression based on the third lactation gives the same error as that based on the second.

SUMMARY AND CONCLUSIONS.

A study of records for 225 Ayrshire cows which had completed five or more lactations was undertaken to determine the relative accuracy of individual records or combination of records as indices of the producing ability of a cow. Milk and fat yields were treated separately and on the same lines. The following conclusions are drawn.

From an analysis of the coefficients of variation it was found that for both milk and fat yields, the first and fifth lactations are the most variable, while the fourth and second are the least variable. The coefficients of variation in the case of fat yield are generally higher than the corresponding figures for milk yield, probably because of the additional source of variation introduced by the error of estimating the butterfat percentage.

A consideration of individual records of the same cow showed that each record is most highly related to the one which follows or precedes it. The greatest correlations exist between the third and fourth and the second and third. Correlations of the first and fifth lactations with other records are comparatively low. This may be largely due to the fact that these two records are the most variable.

Correlations between individual records and the average/

average of all five were high, indicating that the producing ability of a cow may be estimated with considerable accuracy from any one of her individual records.

The highest lactation completed is the one which is most highly correlated with the average of the five. This shows that the highest record gives a very good estimate of the average yield which the cow might be expected to give over a lifetime of five normal lactations.

As there are invariably few records available, and as the third and second lactations are highly correlated with the lifetime average yield, either of these would, in the absence of further records, be sufficiently reliable for the evaluation of a cow.

The relatively low correlation established between the average and the first lactation shows that although this record is widely used, presumably because it is most often available, in selection and particularly in progeny testing of bulls, it is nevertheless the least reliable and deductions from it are most likely to be misleading.

From a comparison of correlations obtained in the study of milk yields with the corresponding values for fat yields it was observed that although the values for the latter are lower the general trend is the same and the same conclusions can be drawn.

The influence of inter-herd differences was determined and they were found to affect significantly both/

both milk and fat yields.

Analyses of variance and covariance were carried out in order to determine the standard deviations and correlations within herds. As was expected, when inter-herd differences were eliminated the correlations between records of the same cow and between individual records and the lifetime average yield were lower. The most probable explanation of this is that in a particular herd various causes are likely to affect the different lactations for the same cow in the same way.

In order to enable the breeder to estimate any missing record or the lifetime average yield of a cow, regressions of individual records on each other, regressions of the average of the five on each of the lactations, and regressions of the average on combinations of these records were calculated. The errors involved in each of these estimations were also determined.

This was done for both milk and fat yields.

It was found that in estimations of the average lifetime yield from a single lactation, calculations based on the third lactation involved the least error. As the number of lactations introduced into the estimation increases the error decreases, but estimations based upon the third lactation involves almost the same error as those based on the first and second lactations/

lactations together.

It may be concluded that in evaluating the producing ability of cows for selection and progeny testing, greatest importance should be attached to the third and least to the first lactation.

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PART III.

<u>EFFECT OF ENVIRONMENT ON PROGENY TEST.</u>

CONTENTS.

INTRODUCTION.

The question of progeny testing has been the subject of much discussion during recent years and many research workers have attempted to solve the problems which the breeder has to face in the application of this method. As yet, however, there is a wide divergence of opinion as to what is the best method of evaluating a dairy bull.

The purpose of the present study is to estimate the influence of environment on the value obtained for a bull by calculation from the production records of his progeny.

Before describing the method followed and the results obtained the following points must be considered:-

1. Methods of evaluating dairy bulls.
2. Minimum number of daughters necessary to evaluate a sire.
3. Reliability of milk records and the use of these records in evaluating the producing ability of a cow.

1. Methods of Evaluating Dairy Bulls.

There are several ways in which dairy bulls can be evaluated as far as their ability as sires of milk-producing cows is concerned. Lack of space forbids a detailed review of any but the most satisfactory

or/

widely-used of the methods so far proposed. These methods are markedly different, as each has its particular faults and no one can be considered entirely satisfactory.

(1) Sire = average production of daughters - average production of dams.

This index was first used by PEARL, GOWEN and MINER (1919). It can be adopted where records of every daughter of a bull, as well as the records of the dams of those daughters, are known. As it is rarely, if ever, possible to get this, comparisons must be made with less extensive data. One of the disadvantages of this method lies in the fact that (on the calculation of the daughter - dam figure) the quality of the dam is neglected, i.e. a bull which is responsible for an increase of 1,000 lbs. of milk on dams averaging 5,000 lbs. is considered equal in merit to one bringing about the same increase on dams averaging 10,000 lbs. The figure allotted to the sire (+1,000 lbs.) gives in itself no true estimate of his worth.

(2) Sire = daughters' average production + the increase of daughters' average production over dams' average production.

This index was proposed by HANSON in Sweden nearly twenty-five years ago. It is the same method as that applied/

applied by YAPP (1924) to fat-corrected milk. T.E. WOODWARD used this undex in 1922 in Guernsey fat records. It is also recommended by LUSH (1933), who states that since the offspring tend to average midway between the parents, inheriting equally from both, the simplest index which would include those facts is that compiled by adding to the daughters' average the increase of the daughters over their dams. This index is known as the equal parent index (LUSH) or intermediate index (RICE, V.A.)

(3) When the production of daughters exceeds that of their dams:-

$$\text{Milk index} = D + 0.429 \quad (D - d)$$

$$\text{Fat index} = D + 1.5 \quad (D - d)$$

When the production of dams exceeds that of their daughters:-

$$\text{Milk index} = D - 2.333 \ (d - D)$$

$$\text{Fat index} = D - 0.677 \ (d - D)$$

Where D = the average production of daughters

d = the average production of dams

This index is simply the "equal parents index" from which the factor constructed under the misconception of allowing for the effects of dominance is omitted. It was suggested by GOODALE and is at present used/

used at Mount Hope Farm. The fractions used in such an index cannot be generally accepted, as they were calculated by GOODALE from a particular series of cross-breeding experiments.

(4) Sire = average production of daughters.

Many papers have appeared in recent years advocating the evaluation of dairy sires from the production of their daughters alone. GIFFORD (1930) shows that this index represents with reasonable accuracy the transmitting ability of a sire. EDWARDS (1933) examined sire indices for their accuracy in evaluating a dairy bull and found that the average production of the daughters is the most satisfactory.

The special weakness of the average production of the daughters as a sire index is that it makes no allowance for differences in the merit of the cows to which the different bulls are bred. However TURNER'S proof of the small assessable part which the dam plays in the inheritance may provide justification for neglecting the yield of the dams.

This index is of great importance as it enables us to use all records available for all daughters, whether or not they are out of tested dams. At the same time it overcomes the difficulty present in all methods where account is taken of the yields of dams, namely, that daughters and dams may be maintained in different environment.

2. Minimum Number of Daughters Necessary to Evaluate a Sire.

Each daughter receives from her sire a sample half of his inheritance and therefore, as the number of daughters increases, a more exact representation of the sire's genetical constitution is obtained. This of course only holds when no selection has been practised, a point which is of supreme importance in progeny testing. There arises the question as to what is the minumum number of daughters necessary to test a bull.

DAVIDS (1925) and GIFFORD (1930) have found that six cows is the minimum number to give a reliable estimate. LUSH (1933) states that "it seems undesirable to publish any sire index based on fewer than five daughters (more than that if the dams are not taken into account)." EDWARDS (1933) found that the minimum number of unselected daughters necessary to give a reasonably accurate indication of their sires' transmitting ability is six.

3. Reliability of Milk Records and the Use of These Records in Evaluating the Producing Ability of a Cow.

It is generally recognised that one of the most important factors in the genetic improvement of dairy cattle and particularly in progeny testing is the adoption of a system by which the milking capacity of a cow can be accurately measured.

This/

This is achieved by an accurate method of recording. The reliability of the different systems of milk recording has been investigated in Part I of this study. The next step is to determine the relative accuracy of the individual records made by a cow or combinations of these records as indices of her producing ability. This subject has been investigated in Part II.

As has already been noted, the relatively low correlation established between the average of five lactations and the first lactation shows that although the latter is widely used in progeny testing, it is nevertheless the least reliable and deductions from it are most likely to be misleading.

The author wishes to give further evidence of this by the following example.

Bull (A) is a pure Ayrshire sire which has 24 tested daughters. Each daughter was recorded under the Scottish Milk Recording Scheme for at least three lactations. All the animals were kept under the same environment and methods of husbandry. No selection was practised and consequently all the daughters of this bull were included in the study. Table 1. gives/

TABLE 1./

TABLE 1.

Number of daughters of Bull A. and their available records.

Number of lactations.	Number of daughters.
3	10
4	7
5	7
Total	24

gives the number of daughters and the records available. The transmitting ability of the sire was assessed in two ways.

First: From the first lactation of each of the daughters the average of five lactations was estimated using the formula established for this purpose (Part II). Then the mean of the averages of all the daughters was taken to indicate the value of the bull. The value obtained by this method was found to be 9028 ± 345 lbs. of milk.

Second: All the records available for each daughter were used in the estimation of the average of her five lactations - when five records were available the arithmetic average was taken directly, while when there were three or four, the formulas given in Part II of this study were used in the estimation. Finally, the average of all daughters was taken and the figure obtained as a value of the sire was found to be

8121/

8121 ± 294 lbs. of milk.

As the milking capacity of a cow can be more accurately measured when more of her lactation yields are available, the value obtained by the second method is more reliable. It will be observed that the estimation of the value of a bull from the first lactations of his daughters is misleading, as the difference between the two estimates is greater than twice its standard error (907 ± 453 lbs. of milk).

EFFECT OF ENVIRONMENT.

Since the production of a cow depends upon the environment to which she is exposed as well as upon her genetical constitution, it is likely that the value of the transmitting ability of a bull as judged by his daughters' production will vary with variation in environment.

In the present investigation the effect of environment on the progeny test has been considered. On Cockburn Farm, which is under the management of the Institute of Animal Genetics, five groups of cows are kept under as nearly as possible identical environmental conditions. In each group the cows are half-sisters by a common sire. Each of these five bulls has another group of daughters on another farm, where management and environment are different from those of/

at Cockburn. Care was taken when assessing the value of each bull to include all his daughters. All the cows, whether they are on Cockburn Farm or on any of the other five farms, are tested under the Scottish Milk Recording Scheme, a full description of which was given in Part I of this study.

The method adopted in evaluating the transmitting ability of a sire is as follows:
First, for each daughter the yield during the lactations available was transferred to the average of five lactations (lifetime yield), as described in Part II. In the case of cows which have completed five normal lactations no formula was needed and the average was obtained in the simple arithmetic way. Then the average production of the progeny of each bull was taken as a value of his transmitting ability. The number of six cows was taken as a minimum. Table 2 gives the number of daughters of each bull both at Cockburn and the other farm. As it is desirable to treat the information confidentially, the five bulls are represented by the letters B, C, D, E and F. Records for milk and fat yields were treated separately and on the same lines. Two values were obtained for each bull: the first value derived from his daughters at Cockburn Farm, and the second from their half-sisters by the same bull on the other farm.

Table 3 gives the results in the case of milk yield/

yield. It will be seen that the difference between the two estimates of the same bull amounted in one case to 1500 lbs. of milk. The values for probability as obtained from FISHER'S tables indicate that the practical value of progeny testing is undoubtedly affected by environment. A figure credited to a bull on one farm might not be reached by his daughters on another farm.

TABLE 2.

Number of daughters available for each bull.

Bull	Number of daughters.	
	Cockburn	other farm.
B	22	25
C	11	10
D	7	14
E	6	23
F	10	20

TABLE 3.

Comparison of 5 groups of cows in Cockburn with their half-sisters on different farms.
(Milk Yield)

Bull	Cockburn Farm			Other farms			Difference	Probability
	Number of daughters	Standard deviation	Average of 5 lactations	Number of daughters	Standard deviation	Average of 5 lactations		
B	22	1077 lbs	9110 ± 235 lbs	25	1060 lbs	9740 ± 216 lbs	630 ± 319 lbs	95%
C	11	2585 "	10510 ± 815 "	10	888 "	9010 ± 296 "	1500 ± 867 "	90%
D	7	1573 "	7830 ± 641 "	14	1282 "	9200 ± 355 "	1370 ± 733 "	93%
E	6	1054 "	9660 ± 471 "	23	1090 "	9810 ± 232 "	150 ± 525 "	25%
F	10	1367 "	9910 ± 456 "	20	1374 "	10610 ± 315 "	700 ± 554 "	80%

Comparing the merit of the five bulls on Cockburn Farm, it will be observed that Bull D evaluated by his daughters' production is inferior to the other four. The same bull on another farm did quite as well as the others. A comparison of the standard deviations found for the yields of two groups of half-sisters shows that in some cases one might amount to three times the other, in the instance of 2585 lbs. of milk as against 888 lbs. This shows that the range of variation of the yields of the daughters of a bull on one farm might be significantly different from that of another group from the same bull on another farm.

Table 4 shows figures for fat yield. Similar conclusions can be drawn.

TABLE 4.

Comparison of 5 groups of cows in Cockburn with their half-sisters on different farms (Fat yield)

Bull	Cockburn Farm			Other farms			Difference	Probability
	Number of daughters	Standard deviation	Average of 5 lactations	Number of daughters	Standard deviation	Average of 5 lactations		
B	22	43.0 lbs	359.8 $\pm$ 9.4 lbs	25	45.5 lbs	396.0 $\pm$ 9.3 lbs	36.2 $\pm$ 13.2 lbs	99%
C	11	84.3 "	407.5 $\pm$ 26.7 lbs	10	39.3 "	355.5 $\pm$ 13.1 "	52.0 $\pm$ 29.7 "	90%
D	7	64.9 "	322.0 $\pm$ 26.5 "	14	55.3 "	372.3 $\pm$ 15.3 "	50.3 $\pm$ 30.6 "	90%
E	6	42.0 "	386.0 $\pm$ 18.7 "	23	47.7 "	388.1 $\pm$ 10.2 "	2.1 $\pm$ 21.3 "	10%
F	10	54.9 "	387.1 $\pm$ 18.3 "	20	50.9 "	426.1 $\pm$ 11.7 "	39.0 $\pm$ 21.7 "	90%

SUMMARY AND CONCLUSIONS.

The methods of evaluating the transmitting ability of dairy bulls, the minimum number of daughters necessary to prove a sire, and the reliability of milk records and the use of these records in evaluating the milking capacity of a cow has been discussed.

Additional evidence is presented to show that the evaluation of a bull from the first lactations of his daughters might be misleading.

A comparison of five groups of cows, each by one bull and all maintained in the same farm so that environmental conditions are constant, with their half-sisters by the same bulls on five different farms suggests that, from the practical point of view, environment may affect the estimate of the transmitting ability of a bull as measured by the production of his daughters.

Further research is needed to throw more light on this question.

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